Modelling Motorcycles Driving Cycles and Emissions in Edinburgh

A thesis submitted in partial fulfilment of the requirements for the award of

Doctor of Philosophy

By

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Abstract

The level of ownership and use of motorcycling has increased rapidly in Edinburgh and the UK in the last ten years. In this study, motorcycle driving cycles (rural and urban) were developed for Edinburgh (Edinburgh Motorcycle Driving cycle-EMDC). The analysis of EMDC demonstrates that motorcycles' driving behaviour differs between urban and rural areas. EMDC shows a typical transient nature of speed, acceleration and deceleration, which is also different from regulatory driving cycles (Economic Commission for Europe-ECE and World Motorcycle Test Cycle-WMTC) and examples from Asia (Taiwan, Bangkok and China). This research underlines the need for detailed investigations of driving cycles in any local condition. It is not generally feasible for a driving cycle developed in one area to be applicable in another area, even with some similar characteristics.

Emission factors were also estimated using onboard, laboratory and micro simulation measurements along the test corridor (Air Quality Management Area-AQMA). Laboratory measurements were carried out by applying a number of standard driving cycles (ECE and WMTC) and the derived EMDCs.

Results show that the emission factors (EFs) calculated in the laboratory for carbon monoxide (CO) and Hydrocarbons (HC) are higher for the urban EMDC cycle compared to the standard regulatory factors than they are for the rural (except Nitrogen Oxide-NOx). Laboratory emission factors for CO and HC for the urban EMDC were found to be higher than the micro-simulation and onboard methods. EFs obtained from micro-simulation and onboard emissions using the National Atmospheric Emission Inventory (NAEI) emission coefficients were not very different with the exception of NOx, which were relatively higher than those of EMDC.

Micro simulation models were mainly developed for private cars and therefore special care should be taken when using them for modelling other conditions (e.g. motorcycles driving characteristics). This study illustrates the extent to which micro-simulation may be utilised to accurately model emissions and discusses the refinements required to model motorcycle motion (hence emission) accurately in micro simulation.

The study provides a platform for a large number of potential future applications for the evaluation of emissions and for developing various policy scenarios of pollution reduction and reducing health impacts at local levels.

Declaration

I hereby declare that this thesis together with work contained was achieved by myself, and contains no material that has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due acknowledgement to others has been made.

(Ravindra Kumar)

Signature...

Date ....

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Dedication

This thesis is dedicated to my father Late Satya Narain Chaudhry, who died on 14 February 2009 (St. Valentine Day). He was not only my father, but also the main source of inspiration and support to continue into higher education and get a PhD since my childhood. All this work would have not been possible without his unconditional love and kind support.

Papa, I always remember my bad days and good days with you. I will always admire your continuous efforts and encouragement to continue my education without which I would have not been here today. You are not in this world any more but you have given me tremendous reasons to achieve my target. I will always need your blessing and love from wherever you are. May God allows your soul to remain in peace and bless me for courage and strong hope for my future!

(Ravindra Kumar)

Signature..

Date ....

LIST OF ABBREVIATIONS

AADT : Average Annual Daily Traffic

AAPE : Average Absolute Percentage Error

ADC : Anchorage Driving Cycle

AECC : Association for Emissions Control by Catalyst

AFR : Air Fuel Ratio

AQS : Air Quality Strategy

AQMA: Air Quality Management Area

ARTEMIS: Assessment and Reliability of Transport Emission Models and Inventory Systems

BDC : Bangkok Driving Cycle

BS : British Standards

CADC : Common ARTEMIS Driving Cycle

CARB : California Air Resources Board

CAT15-Caterpillar Truck model 15

CFR : Code of Federal Regulations

CO_2 : Carbon dioxide

COPERT III: Computer Programme to Calculate Emissions from Road Transport

CORINAIR: CORe Inventory of AIR emissions

COV : Coefficient of Variations

CMEM: Comprehensive Modal Emission Model

CRRI : Central Road Research Institute, New Delhi

CVS : Constant Volume Sampling technique

DFT : Department for Transport

DMRB: Design Manual for Roads and Bridges

DRIVE: Dedicated Road Infrastructure for Vehicle Safety in Europe

DTT : Distribution of Travel Time

DVLA : Driver and Vehicle Licensing Agency

EC : European Commission

ECE : European-Driving Cycle

ECC : Edinburgh City Council

EDC : Edinburgh Driving Cycle

EMDC : Edinburgh Motorcycle Driving Cycle

EPA : Environmental Protection Agency

EU : European Union

FHB : Fachhochschule Biel Cycles

FTP : Federal Test Procedure

GEH : Geoffrey E. Havers

GPS : Global Positioning System

GRPE : Group of Experts on Pollution and Energy

GTR : Global Technical Regulations

HC : Hydrocarbon

HHDDT: Heavy Heavy-Duty Diesel Trucks

ICE : Internal Combustion Engines

IMC : Improved Driving Cycle

IM 240 : U S Environmental Protection Agency Inspection and Maintenance 240 driving cycle

IMMA: International Motorcycle Manufacturer Association

INRETS: The French National Institute for Transport And Safety Research

IPC : Integrated Pollution Control

ITS : Intelligent Transportation Systems

KHM : Kaohsiung Metropolitan Area

LA : Los Angeles

LIDAR: Light Detection and Ranging

LOS : Level of Service

MEASURE: Mobile Emission Assessment System for Urban and Regional Evaluation

MEL : Mobile Emission Laboratory

MOVES: Motor Vehicle Emission Simulator

Modem : Modelling Of Emissions and Consumption In Urban Areas

OBD : On-Board Diagnosis reader

OECD : Organization for Economic Co-operation and Development

PAHs : Polycyclic Aromatic Hydrocarbons

PCD : Pollution Control Department

PEMS : Portable Emissions Measurement Systems PB : Performance Box

PTWs : Powered Two Wheeler

QA/QC : Data Quality Assurance and Control

NAEI : National Atmospheric Emissions Inventory

NEDC : New European Driving Cycle

NOx : Nitrogen Oxide

NRC : National Research Council

NYCC : New York City Cycle

RMS : Root Mean Square Error

R^2 : Coefficients of Correlation

RSD : Remote Sensing Devices

SAFD : Speed Acceleration Frequency Distribution

SFTP : Supplemental Federal Test Procedure

SCOOT: Split Cycle and Offset Optimisation Technique

SD : Standard Deviation

SD card: Secure Digital card

SEPA : Scottish Environment Protection Agency

SMPS : Scanning Mobility Particle Sizer

THC : Total Hydrocarbon

TMDC : Taipei Motorcycle Driving Cycle

TNO : Netherlands Organisation for Applied Scientific Research

TWC : Three way Catalyst Technology

TRL : Transport Research Laboratory

TU Graz: Technical University Graz

UDC : Urban Driving Cycle

UC : California Unified Cycle

UN : United Nation

URTRAP: Urban Road Traffic and Air Pollution

USEPA : US Environmental Protection Agency

VOC : Volatile Organic Carbon

VROM : Netherlands Ministry of the Environment

WMTC : World Motorcycle Test Cycle

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CHAPTER 1 BACKGROUND OF THE STUDY

1.1 General

The European Environment Agency defines air pollution as ‘the presence of contaminant or pollutant substances in the air at a concentration that interferes with human health or welfare, or produces other harmful environmental effects’. Air pollution has historically been caused by industrialisation and the consequent proliferation in the use of ‘fossil fuels’ (and therefore sulphur dioxide emissions) in the industrial process and the central process for most electricity generation, heating systems and motor vehicles. There is a vast range of air pollutants, which cause a variety of effects on the environment and health.

Air quality is key to the health of humans and ecosystems. Air pollution can lead to a variety of respiratory diseases, tuberculosis, bronchitis, heart and chest diseases, stomach disorders and cancers. There is also a growing recognition of the links between atmospheric problems such as local air pollution, acid rain, global climate change and stratospheric ozone depletion. Air pollution is worst in Latin America and Asia. For example, in Seoul and Mexico City the air quality is so bad that some people wear facemasks to filter the air[1].

1.2 Air quality problems in the UK

Traffic is the major air polluter, with traffic fumes accounting for just over half of the total domestic nitrogen emissions. Petrol and diesel-engine motor vehicles emit a wide variety of pollutants, mainly carbon monoxide (CO), nitrogen oxides (NO_X), hydrocarbon, volatile organic compounds (VOCs) and particulates (PM_{10} particulate matter having a diameter <10μm), which have an increasing impact on urban air quality.

Another EU National Emission Ceilings Directive sets ceilings for each Member State for emissions of ammonia, oxides of nitrogen, sulphur dioxide and volatile organic

1(Downloadable, http://www.politics.co.uk/briefings-guides/issue-briefs/environment-and-rural-affairs/air-pollution-$366647.htm, Accessed on 6th May 2009) compounds (VOCs). These four pollutants are primarily responsible for acidification, eutrophication and ground-level ozone. The ceilings must be met by 2010.

The European Union (EU) Air Quality Framework Directive (96/62/EC) defines the policy framework for 12 air pollutants known to have a harmful effect on human health and the environment. The limit values for the specific pollutants are set through a series of Daughter Directives. A new Air Quality Directive came into force in June 2008, and will be transposed into national legislation by June 2010[2]

The UK has the worst road pollution in Europe — hundreds of local authorities are found breaking EU limits on fumes, which can harm public health and cause conditions like asthma, heart problems, lung cancer and premature death. The exhaust on certain stretches of roads break safety levels in 95% of cities and areas in the UK. One of the reasons UK is doing badly is due to a large population living in a relatively small area compared to many other European countries. UK has been warned by the European Commission for failing to comply with EU standards on air quality and EU air pollution laws, and could be forced to pay large fines unless it takes action to cut traffic pollution. The report also states that the UK will miss its EU targets to reduce the amount of nitrogen dioxide produced to safe levels by 2010[3].

1.2.1 Impact of air pollution

The impacts of air pollution can range from poor air quality in the close vicinity of a source to the disruption of natural chemical cycles and physical processes that occur on a global scale. The environmental impacts of air pollution range from local level to global level. The properties, which are attributable to the different environmental impacts are presented in Table 1.1.

2(Downloadable,http://www.politics.co.uk/briefings-guides/issue-briefs/environment-and-rural-affairs/air-pollution-$366647.htm).

3 (Downloadable, http://news.bbc.co.uk/cbbcnews/hi/newsid_7910000/newsid_7917600/7917625.stm. 2009).

Table 1.1 Different environmental impacts of air pollution

Level	Environmental impacts
Local	Reduction of local air quality – affecting human health and vegetation growth, and causing damage to materials
	Acid deposition – leads to degradation of the terrestrial environment
Regional	Photochemical oxidants – reduce local air quality (as above).
Global	Enhanced greenhouse effects – leading to greater climate change. Destruction of stratospheric ozone – causing increased UV radiation at the earth's surface

Air pollution adversely affects health, ranging from mild irritation through increased symptoms for those with pre-existing respiratory problems to premature mortality. In the UK air quality standards have been established based on expert medical advice on what is likely to affect human health. Long-term exposure to air pollutants is also likely to negatively impact on health. Poor air quality reduces life expectancy in the UK by an average of seven to eight months, with equivalent health costs estimated to be up to £20 billion a year (The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, Volume 2, 2007). However, continuous improvements between 1990 and 2001 in emission reduction have helped to avoid an estimated 4,200 premature deaths per year and 3,500 hospital admissions per year. The UK Air Quality Strategy aims to improve the reduced life expectancy impact to five months by 2020 by minimising air pollutant emission (Part IV of the Environment Act 1995 Local Air Quality Management, 2009).

The latest projections produced in support of the UK Air Quality Strategy (AQS), predict that the UK will fall short of meeting EU legally binding air quality objectives for concentrations of nitrogen dioxide (NO_2) and particulate matter (PM_{10}) in a number of geographical areas (mostly in urban areas and busy roads). The objective for ozone (O_3), of which nitrogen dioxide (NO_2) is one of the two main precursors, is also unlikely to be met in large parts of England and Scotland. Oxides of nitrogen (NO_X) emissions also contribute to the formation of secondary particulate matters; NO_X control measures therefore make a contribution towards meeting air quality objectives on PM_{10} and $PM_{2.5}$

(for which an exposure reduction target has recently been adopted under EU Directive 2008/50/EC).

Hydrocarbons (in the form of volatile organic compounds) also contribute to the formation of ground level ozone. Exposure to high levels of ozone may cause slight irritation to the eyes and noses. If very high levels of exposures are experienced over several hours, damage to the airway lining followed by inflammatory reactions may occur. Carbon monoxide substantially reduces the capacity of the blood to carry oxygen: people who have an existing disease that affects the delivery of oxygen to the heart or brain are likely to be at particular risk if these delivery systems are further impaired by carbon monoxide (DFT, 2006).

1.2.2 Sources of air pollutants

Electricity and heat production (e.g. at power stations) constitutes the main source of sulphur oxides (SO_X) emissions (58.4 %), followed by manufacturing industries and construction sources (14.3 %). SO_X is an acidifying pollutant, which can also aggravate respiratory diseases. In contrast, agricultural activities are responsible for the vast majority of ammonia (NH_3) emissions in the EU-27. Livestock manure, together with emissions from the application of fertilisers account for more than 90% of NH_3 generation (European Environment Agency, 2008). Ozone levels during the summer of 2007 were among the lowest in the past decade. The highest one-hour ozone concentration of 479 microgram/m^3 was observed in Italy on the island of Sicily, while the second highest level of 363 microgram/m^3 was observed in Romania. (Source: European Environment Agency, 2008). Road vehicles are a major source of air pollution in urban areas, responsible for over half the nitrogen dioxide emissions and over 75% of carbon monoxide in the UK (Defra, 2008).

Air pollutants are contributed by activity from different sources such as road transport, business, residential homes, and energy supply; 22% of this total is contributed by road traffic, as shown in Figure 1.1. Latest estimates show that, despite significant improvements in this sector, road transport still accounted for 37% of total United Kingdom NO_X emissions in 2004, of which 15% was from light vehicles. Nitrogen dioxide is formed in a city environment from a build up of NO_X, helping formation of particulate matter (DfT, 2007). For PM_{10} emissions road transport account for 22% of the total UK emissions, of which light vehicles contributed 12%. The contribution of vehicle emissions to air pollution is even higher in urban areas than is indicated by their contribution to the UK total. If emissions of finer particles are considered, the contribution of the transport sector in 2001 was 39% of total UK emission of $PM_{2.5}$ and 54% of total UK emission of $PM_{0.1}$ (by far the biggest source in the UK).

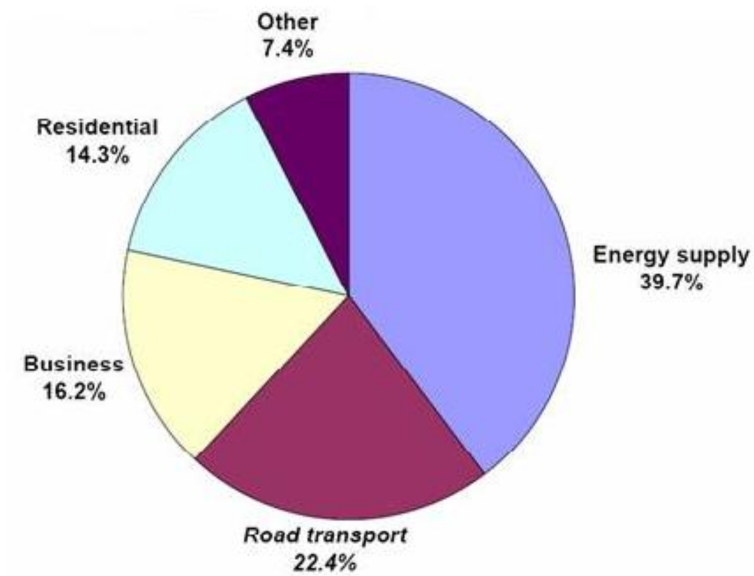


Figure 1.1 Contribution of traffic to air pollution

Edinburgh city council has reported that 88% of nitrogen oxides come from road transport, with the remaining 12% coming from domestic heating and Edinburgh International Airport. Different vehicles give off different amounts of nitrogen oxides. Larger and older vehicles, particularly diesel, produce more nitrogen oxides than new vehicles. New vehicles are ‘cleaner’ because of new technology, such as catalytic converters (ECC, 2006).

1.2.3 The UK’s climate change programme

Climate change is the greatest environmental challenge facing the world today. Rising global temperatures will bring changes in weather patterns, rising sea levels and increased frequency and intensity of extreme weather. The UK has passed legislation, which introduces the world's first long-term legally binding framework to tackle the dangers of climate change. The Climate Change Bill was introduced into Parliament on 14 November 2007 and became law on 26th November 2008. Climate Change Act 2008 has set a target for the year 2050 for the reduction of targeted green house gas emissions.

This Act has made law for greenhouse gas emission reductions through actions in the UK and abroad of at least 80% by 2050, and reductions in CO_2 emissions of at least 26% by 2020, against a 1990 baseline. The 2020 target will be reviewed soon after Royal Assent to reflect the move to all greenhouse gases and the increase in the 2050 target to 80%.

This Act enables the Government to report to Parliament about carbon budgeting policy and proposals to meet the budget as soon as possible. Under this Act, a Committee on Climate Change has to be established to confer powers to establish trading schemes for the purpose of limiting greenhouse gas emissions or encouraging activities that reduce such emissions or remove greenhouse gases from the atmosphere. Financial incentives and adaptation to climate change to produce less domestic waste and to recycle were considered [4]

In response to increasing concerns about climate change, the United Nations Framework Convention on Climate Change was agreed at the Earth Summit in Rio de Janeiro in 1992, and 184 countries have now signed it. Under the Convention, all developed countries agreed to aim to return their greenhouse gas emissions to 1990 levels by 2000. The UK will be one of a small number of Organizations for Economic Co-operation and Development (OECD) countries who will meet this target.

1.2.4 Emissions and fuel consumption estimation from transport by National Atmospheric Emission Inventory (NAEI), UK

The National Atmospheric Emission Inventory (NAEI) is the standard reference for air emissions for the UK and provides annual estimates of emissions for a wide range of important pollutants, including air quality pollutants, greenhouse gases, regional pollutants leading to acid deposition and photochemical pollution, persistent organic

4. http://www.defra.gov.uk/environment/climatechange/ downloadable 11 April 2009).

pollutants and other toxic pollutants such as heavy metals. A spatial disaggregated 1x1 km inventory is produced each year.

Hot exhaust emissions and fuel consumptions are calculated within the NAEI using factors for each vehicle type based on the composition of UK's average vehicle fleet (age profile and fuel mix) from the Driver and Vehicle Licensing Agency (DVLA) national licensing data centre.

Fuel consumption and emission factors expressed in grams of fuel or emissions respectively per kilometre driven as well as traffic data for each of the six classes of vehicles are used to estimate national fuel consumptions and emissions from passenger cars, light goods vehicles (LGVs), rigid heavy good vehicles (HGVs), articulated HGVs, buses/coaches and mopeds/motorcycles. The vehicle classifications are further sub-divided according to fuel type (petrol or diesel) and the regulatory emission standards when the vehicle are manufactured or first registered.

The vehicle Euro emission standards apply to the pollutants NO_X, CO, particulate matters and hydrocarbons but not to CO_2 or fuel consumption. Nevertheless, the Euro standards (pre-Euro 1, Euro 1, Euro 2 and Euro 3) are a convenient way to represent the stages of improvements in vehicle or engine design that have led to improvements in fuel economy and to the age and composition profile of the fleet.

Fuel consumptions and emission factors are expressed in grams of fuel or emissions respectively per kilometre driven for each detailed vehicle class and are taken from two distinct data sources:

(i) Vehicle emission test data provided by the Transport Research Laboratory (TRL) over different driving cycles from measurements on a limited sample of vehicles;

(ii) Car manufacturers' data on CO_2 emissions and surveys with freight haulage companies on fuel efficiency of HGVs. However, the amount of fuel that a vehicle consumes depends on many parameters including frequency and rates of acceleration / deceleration, how aggressively the vehicle is driven, how much load is applied to the vehicle's engine, its state of maintenance, tyre inflation and use of air condition.

The fuel consumption factors used in the NAEI calculations are polynomial functions expressing the relationship between fuel consumption rate and average vehicle speed for each class of vehicle. These are based on measurements of fuel consumption and emission rates for samples of in-service vehicles taken off the road and tested under controlled laboratory conditions over a range of different operational drive cycles. The factors used by the NAEI come largely from a database held by the TRL of factors measured over different test cycles that simulate real-world conditions. For the more modern classes of vehicles and technologies that have yet to be tested, some expert judgements are used for calculating emissions and fuel consumptions.

This is especially the case for large HGVs and buses where the test sample size is small; it is very expensive to carry out these tests because they require special facilities. Using average speed of vehicles is itself a crude (but so far the only kind available) indicator to the way a vehicle operates. There could be many different cycles, all with the same average speed, that have different amounts of acceleration and deceleration built into them and for each of these the fuel consumption rate will be very different. Emissions for the key air quality pollutants (NO_X, PM_{10}, $PM_{2.5}$, SO_2, NMVOCs, benzene, 1, 3-butadiene and CO) are calculated using speed-related emission factors multiplied by vehicle flows on the road network. For other pollutants such as CO_2 and heavy metals, fuel consumption is used as a proxy for the distribution of emissions. The fuel consumption maps are calculated from the speed related fuel consumption factors multiplied by vehicle flows.

Part I of the Environmental Protection Act 1990 has established two pollution control systems: (i) the local air pollution control (LAPC) system enforced by local authorities in England, Wales and by the Scottish Environment Protection Agency (SEPA) in Scotland (referred to as ‘local enforcing authorities’) and (ii) an integrated pollution control (IPC) system enforced by the Environment Agency in England and Wales and SEPA in Scotland. Apart from these, the EU has set up policy strategy in relation to the preservation of the ozone layer to implement measures aimed at the phasing-out of emissions of ozone-depleting substances (ODS) in the EU and worldwide. In the shorter term, the objective is to limit the expected peak in the destruction of the ozone layer.

1.3 Relevance of motorcycle emissions in traffic stream

Table 1.2 shows the top eight models of motorcycle in the UK classified by manufacturers and engine type with the hero Hondas at the top. There are approximately 1.26 million licensed motorcycles in Great Britain, including those, which are exempt from vehicle excise duties. The motorcycle ownership rate in 2007 was highest in the South West of England and lowest in Scotland. The ownership rate in Great Britain in 2007 was lower than in any other main EU country at that time, except Ireland and it was estimated that 9.8% of motorcycles in active stock were unlicensed. About 45% of new registrations were for machines up to 150 cc engines and 46% were for machines over 500 cc.

Table 1.2 Top eight models of motorcycles in the UK

Sr. no.	Manufacturer	Description	Type	Engine size (cc)
1	Honda	CBR 125 R	Supersport	124
2	Suzuki	GSXR 1000	Supersport	988
3	Kawasaki	ZX6R	Supersport	636
4	Honda	CBR 1000 RR	Supersport	998
5	BMW	R 1200 GS	Dual Sport	1170
6	Yamaha	YZF R1	Supersport	998
7	Honda	SCV 100 Lead	Scooter	102
8	Piaggio	NRG	Scooter	49

Source: Motorcycle Industry Association, DFT, UK

In 2007, there were 146,000 motorcycles registered for the first time, higher than in the three previous years. Scooters and sports motorcycles were the most popular types of new motorcycles. A total of 957,000 motorcycles went through the MOT test in 2007/08. This represents a large increase from earlier years, as more mopeds and small motorcycles are being tested. The MOT pass rate for motorcycles has increased over the last ten years, and now stands at 82%. Faulty lights remain the most common cause of MOT failure.

Statistics show that motorcycles travelled around 5.6 billion vehicle kilometres in 2006 (Figure 1.2). Motorcycle traffic is generally highest in the summer months and lowest in winter, peaking in July (2003-7). Motorcyclists made fewer trips a week on average in 2006 than they did in 1985-6. However, the distance travelled and the time spent travelling on those trips has increased over the same period.

In general, motorcycle fleets in the UK are 8-9 years old. Larger proportions of engine size categories fall within the engine size of >500 cc (Compendium of Motorcycling Statistics, 2008).

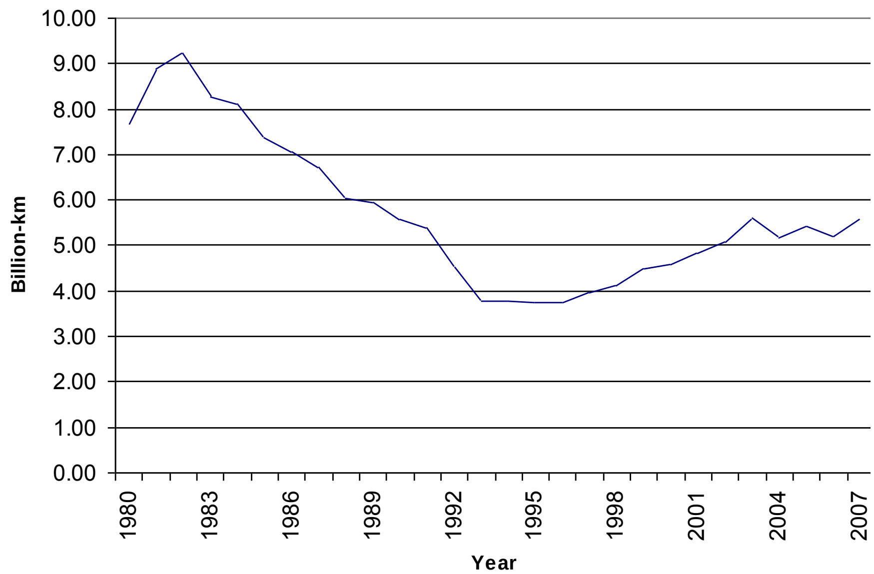


Figure 1.2 Trends of motorcycles travel in the UK

The overall emissions from motorcycles are low in comparison with other road vehicles and are not expected to grow dramatically in mass terms. However, the DfT reports that the average speed of motorcycles is 8 km hr^{-1} faster on single carriageway roads to that of cars on most types of roads. Motorcycle speeding is most common on motorways and dual carriageways in the UK (Compendium of Motorcycle Statistics, 2008).

Significant reductions in emissions from other forms of road transport were brought about by new emission standards and technology, whereas the emissions from motorcycles are an increasing percentage of the total emissions from road transport (DfT, 2007). Vasic et al., (2006) compared the emissions of CO, HC, NO_X and CO_2 between 8 two-wheelers and 15 cars of the Swiss fleet. The powered two-wheelers (include mopeds and motorcycles) on the market in 2001 produced significantly higher emissions of all pollutants except CO_2 than gasoline-powered passenger cars from the same sales period. The emissions for HC and CO were higher than cars in a direct comparison of mean unit emissions (in g/km), mean yearly emissions (in kg/vehicle/year) or fleet emissions (in Tonne/year) in the two-wheelers. NO_X contributions were found to be roughly one-fifth of that of the car fleet and thus not negligible.

The motorcycle exhaust emissions involve much more variations than the cars due to wide variations of engine sizes, ranging from 50 cm^3 to 2000 cm^3. Their power varies from 5 kW to 150 kW, in ready to ride mass from less than 100 kg to nearly 400 kg. In performance, it extends from 100 km h^{-1} to 300 km h^{-1}, while passenger car mass power ratio varies from 35-260 kW/tonne lesser as compared to 20 to >400 kW/tonne of motorcycle (Gense et al., 2003). Comparisons of emission standards of cars and motorcycles of CO, HC, PM and NO_X indicate that emission standards adopted for type approval testing procedures for motorcycles is far behind emission standards for cars in the UK (NAEI, 2007).

In the UK, the NAEI database and other emission factor data from TRL and DBRM are used to estimate the pollution from motorcycles, which is based on European standards. Coefficients are provided for the functions relating emission factor in g/km(gm $km^{-1)}$ to average speed for all the different types and sizes of vehicles in the UK fleet, and in all the categories of European emission standards from pre-Euro1 (pre-1993) right through to Euro 4 (2005) (NAEI, 2007). These standards are not applicable at micro level/local level due to their steady patterns of driving cycle. These comparisons of emission factors have been presented in Table 1.3. The emission standards were adopted based on the European directives found higher than car.

Table 1.3 Comparisons of motorcycle and petrol car emissions factors (40 km h^{-1})

Vehicle Type	Two Wheel				Car		
Emission ($gm\ km^{-1}$) 1999 onward	Moped 2-stroke	< 250 cc 2- stroke	< 250 cc 4- stroke	250-750 cc 4- stroke	Euro 4 < 1.4 l litre	Euro 4 1.4 - 2.0 l litre	Euro 4 > 2.0 l litre
CO	2.264	11.920	7.014	7.045	0.876	0.426	0.087
HC	2.581	6.747	0.828	0.836	0.044	0.031	0.015
NO_X	0.010	0.023	0.203	0.154	0.049	0.101	0.056
PM	0.040	0.040	0.120	0.120	0.001	0.001	0.001
CO_2	2.264	11.920	7.014	7.045	0.876	0.426	0.087

Source: NAEI, 2007

Dynamic characteristics of motorcycle driving characteristics and their emission standards are significantly different from those of the private cars. Different emission standards and mass power ratios of motorcycle engines are the base for developing the independent local driving cycles for motorcycle. Typical dynamics of car and motor bike use in real-world circumstances were compared with the European standard test cycles as shown in Figure 1.3.

Investigations of the dynamics of the driving patterns show that it already lacks sufficient dynamics to represent modern normally driven cars. The criteria used to judge the dynamics used here is RPA (Relative Positive Acceleration) (for an explanation of these parameters see Rijkeboer et al., [2001]). Bikes, even the smaller ones, show the dynamics of sportily driven cars. This turns out to be representative even for Japanese patterns of use, which are generally slower, but not less dynamic than the American or the European motorcycles.

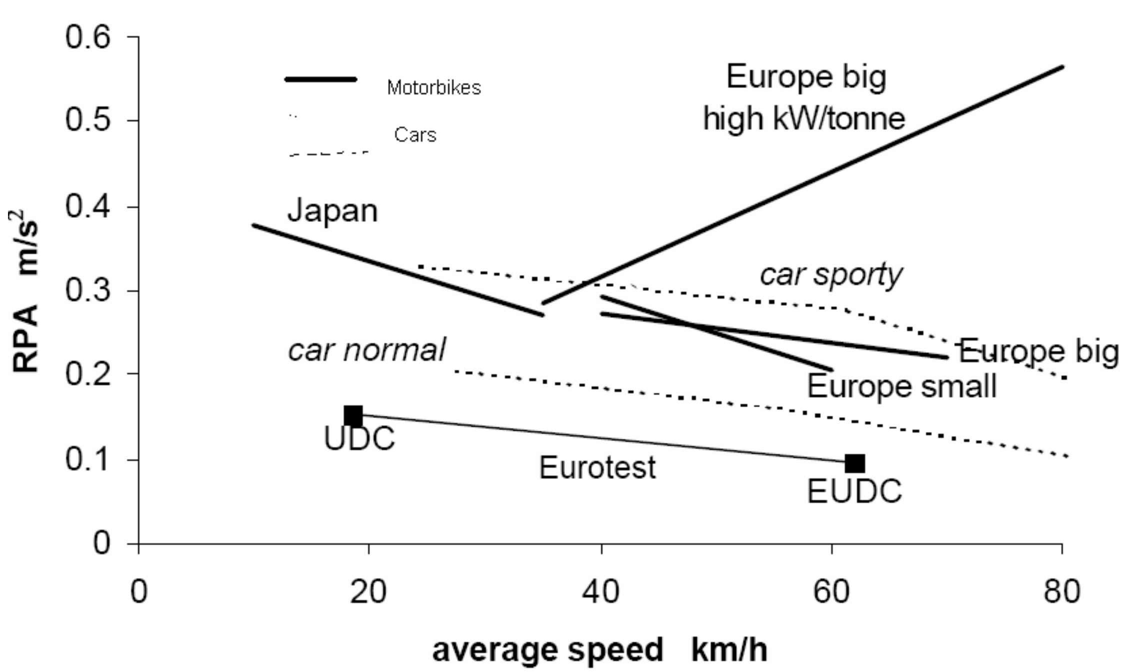


Figure 1.3 Dynamics of car and motorcycles use in real-world circumstances compared to European standard certification test cycles.

Motorcycles with very high power-to-mass ratio (> 200 kW/tonne) surprisingly show increased dynamics with increased speed, within the range of average speed investigated. This was typical for European use only (The Japanese and American conditions are not presented here). As expected, all of these do have influence on emission behaviour. UDC (Urban driving cycle) and EUDC (Extra urban driving cycle) has an influence on relative positive acceleration.

1.3.1 Emission standards for 2- and 3-wheeled vehicles

Chapter 5 of Directive 97/24/EC introduced mandatory emission standards for 2- and 3-wheeled vehicles from 19 June 1999. This category includes mopeds, motorcycles and scooters as well as tricycles and quadric cycles. The emissions controlled are carbon monoxide, hydrocarbons, and oxides of nitrogen (NO_X). From that date manufacturers of such vehicles were required to obtain 'type approval' to the new EU emissions standards for new model types being introduced to the market (EC, Directive 97/24/EC).

This was implemented in two phases: the first, named Euro 1 took place after 2 years of 97/24/EC, Euro 2 take place during a period of 24 months from the adoption of the EC Directive 2002/51/EC, the second, Euro 2 even with tighter limits. From 17 June 2003, all new vehicles of these types entering service in the UK were required to meet these standards. The limits and the classification for the Euro 3 stage (2006) have been introduced in the aforementioned Directive for the European driving cycles as presented in Table 1.4. The World Harmonised Motorcycle test cycle has also been in place since 2006 onward (Table 1.5).

Table 1.4 Current and future European limits

Euro Standard	Type of Engine	CO (gm km^{-1})	HC (gm km^{-1})	NO_X (gm km^{-1})	Driving Cycle	Year
Euro 1 Stage	2-stroke	8	4	0.1	ECE	1999
	4-stroke	13	3	0.3		
Euro 2 Stage	< 150 cc	5.5	1.2	0.3	ECE	2003
	>150 cc	5.5	1	0.3		
Euro 3 Stage	< 150 cc	2	0.8	0.15	ECE	2006
	> 150 cc	2	0.3	0.15		

Table 1.5 Current WMTC limits for motorcycle emissions

WMIC Standard	Classification speed (km h^{-1})	CO (gm km^{-1})	HC (gm km^{-1})	NO_X (gm km^{-1})	CO (gm km^{-1})	Year
WMTC-old (stage 1)	Vmax ≤130	2.62	0.75	0.17	WMTC1	2006
WMTC-old (stage 1)	Vmax ≥130	2.62	0.33	0.22	WMTC1	2006

To ensure the maintenance of emissions performance and to facilitate access to the EU market for manufacturers of non-original replacement catalysts, Directive 2005/30/EC established performance criteria for the type approval as separate technical units of replacement of catalytic converters. As an aid to enforcement, the directive also prescribed requirements for the marking and packaging for both these and original replacement catalysts (i.e. those covered by the original type approval for the vehicle) (EC Directive 2005/30/EC, 2005).

1.3.2 Standards for replacement catalytic converters

Article 2 of directive 2006/120/EC required member states to prohibit the sale or installation on a vehicle of replacement catalytic converters, which had not been type-approved to the emission standards of directive 97/24/EEC as amended. This directive was issued to reduce pollution from new vehicles introduced in recent years. Catalytic converters have been one of the means adopted by manufacturers to meet the tighter standards.

The need for catalysts partly reflects the efficiency of the engine combustion process, so that whilst some smaller engine machines such as mopeds have generally required catalysts from the Euro 1 stage (2003), other larger machines did not require catalysts until the Euro 2 (2004) or Euro 3 stage (2007). The precise requirements for catalysts on these vehicles are very model-specific; however, some of the larger machines may require two or three catalysts. This new measure will help to ensure the performance of catalytic converters offered for use as replacement components (EC Directive 2006/120/EC).

1.3.3 Health impact of motorcycle exhaust

Shing et al., (2002) studied the effect of motorcycle exhaust (ME) on the motor nerve exposing animals to the exhaust by inhalation. ME particulates (MEP) were found to cause adverse effects on the motor nerve, which were associated with a fall in nerve Na^+/K^+-ATPase activity (the Na^+/K^+-ATPase is an ion-translocating membrane protein).

Hui et al., (2003) explored the effects of motorcycle exhaust particulate on vasoconstriction using rat thoracic aortas under organ culture conditions treated with organic extracts of motorcycle exhaust particulate from a two-stroke engine. Motorcycle exhaust particulate extract (MEPE) induced a marked enhancement of vasoconstriction in aortas under organ culture conditions and imply that a ROS–Ca^{2+}–MLCK pathway may be involved in this MEPE-induced response.

A large number of studies have reported that environmental pollutants from fossil fuel combustion can cause deleterious effects to the immune system, resulting in an allergic reaction leading to respiratory tract damage. Lee (2004) investigated the effect of MEPs, a major pollutant, on airway inflammation and airway hyper-responsiveness in laboratory animals in the Taiwan urban area. BALB/c mice were instilled intratracheally (i.t.) with 1.2 mg/kg and 12 mg/kg of MEP, which was collected from two-stroke motorcycle engines. The results shows that the filter-trapped particles emitted from the unleaded-gasoline-fuelled two-stroke motorcycle engine may induce pro-inflammatory and pro-allergic response profiles in the absence of exposure to allergen.

MEPs contain carcinogenic polycyclic aromatic hydrocarbons including benzo(a)pyrene. Ueng, et al., (2005) found that MEP and benzo (a) pyrene was able to induce metabolic enzyme, inflammatory cytokine and growth factor gene expression in CL5 cells and stimulate lung epithelium-fibroblast interaction.

In another study by Lee et al., (2005) MEP was able to induce pro-inflammatory and pro-allergic response profiles in BALB/c mice. Effects of MEP on interleukin (IL)-8 productions in A549 human airway epithelial cells were further investigated. These health impact assessment studies of motorcycle exhaust particle support the base for understanding the motorcycle exhaust (Figure 1.4), even if it is in a minority, for Edinburgh local conditions.

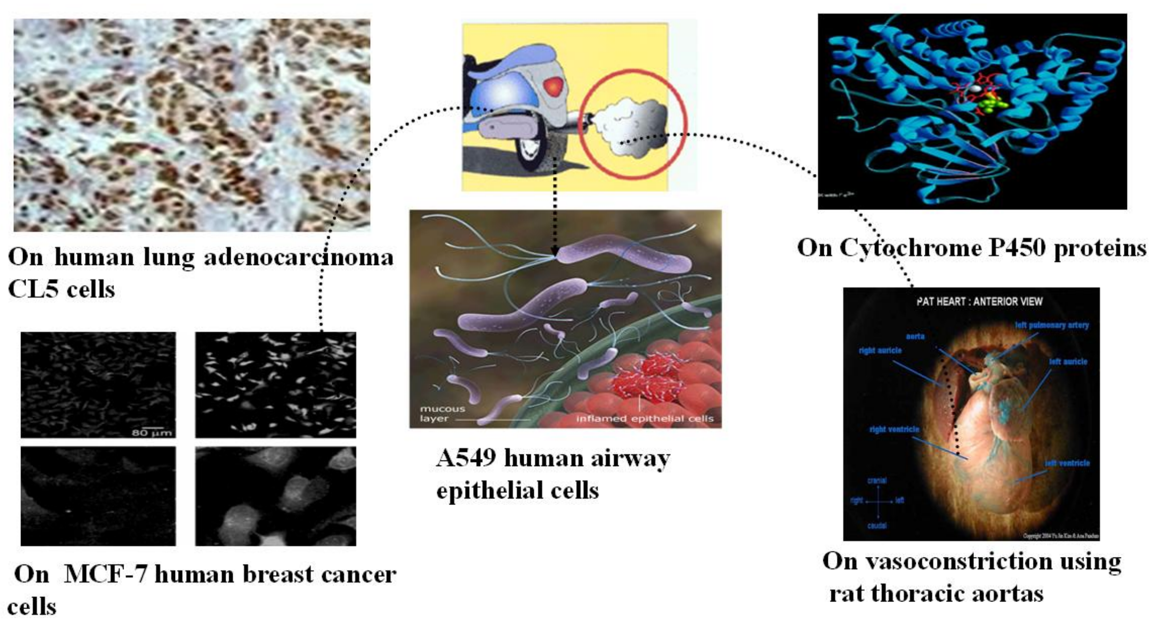


Figure 1.4 Health impact of motorcycle exhaust

1.3.4 Motorcycle ownership in Edinburgh and pollution issues

Motorcycle ownership and percentage trips made are growing rapidly in Edinburgh. Ownership of motorcycles has almost doubled in the last 10 years (DVLA, 2006). Future growth prospects for motorcycle ownership are quite good as per economic investigation in the UK (Duffy and Robinson, 2004). Engine size distribution of motorcycles in Edinburgh is presented in Figure 1.5 below. This shows larger share of engine size is greater than 500 cc.

Edinburgh City Council (ECC) reports eight locations (Queen Street, Princes Street, West Maitland, Street, George Street, Leith Walk, North Bridge, Roseburn Terrace and Gorgie Road in city) where NO_2 levels are likely to be exceeding the average annual limits as adopted by the European Union (ECC, 2006).

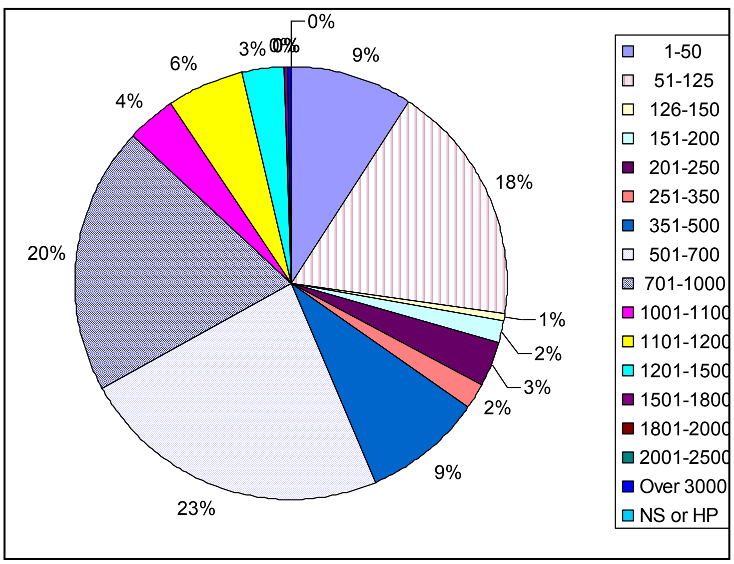


Figure 1.5 Engine size distributions of motorcycles in Edinburgh

NO_X control is very critical for future motorcycle technologies due to the recent adoption of the WMTC (Bosteel et al., 2005). This is especially so for motorcycle engine capacities greater than 600 cc, which produce higher NO_X with higher rates of acceleration, higher maximum speed and the more transient nature of the driving cycle than current cycles. HC and CO emissions are also significantly influenced by the ambient start requirements of future cycles like WMTC and the Euro cycle. In such conditions, the overall contribution of NO_X will be much higher from motorcycles in spite of adopting WMTC/Euro standard emission standards (Bosteel et al., 2005). First time emission standards for motorcycle were implemented in the year 1999. New emission standards (Euro 3 and WMTC from January 2006 for all motorcycles of >150 cc) are far behind the car (Euro 4 Standards from January 2006), in addition to the fact that treatment technologies of motorcycles are not as efficient as in the cars. In spite of all of these factors, there are still no plans at the ECC to estimate or quantify emissions of motorcycles for proper emission control technologies for motorcycles.

1.3.5 Emission and driving cycles

Propulsion of an automobile needs energy, which is in most cases obtained by the conversion of chemical energy from fossil fuels to mechanical energy by means of internal combustion engines (ICE). Hazardous emissions are emitted due to lower efficiency of the machine for combustion causes. Due to the increasing use of automobiles and thereby increasing environmental damage, the automobile industry is required to develop engines with higher efficiency and lower emissions to meet the establishment of emission laws. Connected with this, there arises the need for test procedures to compare several engines with each other. These test procedures are called driving cycles. A driving cycle for a vehicle is a representation of a speed–time sequenced profile developed for a specific area or city. Several researches have investigated the influence of driving cycle on emissions (for example Karavalakis, 2009; Andre, 2004; Chen et al., 2003). Knowledge of the driving cycle is an important requirement in the evaluation of exhaust emissions, as driving cycles are widely used for the estimation of transport air pollutant emissions and in the building of databases for emission inventories. For example, driving cycles for private cars and light goods vehicle (LGV) are used to enhance traffic management systems, determining fuel consumption patterns and reduce transport impacts on health (Tzirakis et al., 2006; Kumar et al., 2007; Saleh, 2007; Hung et al., 2007).

1.4 Summary

The UK has the worst road pollution in Europe. Hundreds of local authorities are breaking European Union limits on fumes, which can harm public health and cause conditions like asthma, heart problems, lung cancer and premature deaths. In Edinburgh city, several locations have been identified, where NO_X emissions are exceeding the EU limits.

Motorcycle ownership and the percentage of trips made are growing rapidly in Edinburgh and ownership of motorcycles has almost doubled in the last 10 years. The emission factors for motorcycles are higher than cars (except CO) and the typical dynamics of motorcycles are different. However, first time emission standards for motorcycles were implemented in 1999. The new emission standards (Euro 3 and WMTC) for all motorcycles of >150 cc, which have only been introduced in 2007 are far behind those for the cars (Euro 4 in 2006). Also, the after-treatment technologies of motorcycles are not as efficient as they are for the cars.

Several researches have investigated the influence of driving cycle on emissions. However, much less research has been carried out on motorcycle driving cycles under local conditions. This illustrates the need for further research on driving cycles under local conditions as well as emission measurements. The motivations, research aim, and research approach are overviewed in the next chapter.

CHAPTER 2 MOTIVATIONS, AIMS AND RESEARCH APPROACH

2.1 Introduction

In congested cities, motorcycles are cheaper and quicker than other conventional transport modes and because they are fewer and smaller in size than cars, they are perceived to be contributing less to fuel consumption and emissions. However, emission factors for motorcycles are higher than for cars, because of lack of efficient technological attachments in motorcycles (e.g. catalytic converters) which affect the overall emission efficiency. The reason for this inefficiency is that there is not enough space in motorcycle engines to allow high temperatures to fully activate the catalytic converter. In addition, the emissions accumulate because of the longer trips made by motorcycles compared to cars. The National Atmospheric Emission Inventory (2008) has shown that motorcycles have about twice the emissions factor (gm km^{-1}) of NO_X, PM and HC than petrol cars. Vasic and Weilemann (2006) established that emissions (gm km^{-1}) of CO, HC, and NO_X are higher for motorcycles than cars (CO_2, however, is greater for cars), and Ntziachristos et al., (2006) reported that motorcycles will generate more than 7% and 20% of CO and HC produced by road transport by 2012, if no remedial measures are taken in Europe.

In Edinburgh, it was found that NO_X emissions exceeded the European Union limits at many locations within the Air Quality Management Area (AQMA). This is partly because of the increased number of motorcycles, buses and cars (City of Edinburgh Council, 2006). Motorcycle ownership has almost doubled in the last decade in Edinburgh (DVLA, 2006).

The dynamic characteristics of motorcycle driving (ability to filter in traffic, moving ahead of queue and manoeuvring in parallel to other vehicle in lanes), are relatively different than those of private cars, and this complex manoeuvring is not much discussed in the literature (Lee, 2008). Motorcycles also perform badly on a per capita basis because of the differences in occupancy and engine size relative to cars. Motorcycles' characteristics such as age, engine type and size, manufacturer and driving characteristics affect emissions (Rijkeboer et al., 2005). In the course of this research study, emission measurements from motorcycles driving considerably different traffic conditions in the city of Edinburgh have been analysed using a number of approaches. This chapter presents the motivations, aim and objectives, research approach and structure of the thesis.

2.2 Motivations of research

Many databases have been created on motorcycle emissions. The European Commission Directives (97/24/EC, 2002/51/EC) established common standards and procedures for evaluating motorcycle emissions as pre-Euro (up to 1999), Euro 1 (from 1999), Euro 2 (from 2003) and Euro 3 (2006). Euro 3 standards for mopeds (fitted with engines smaller than 50 cc) were also implemented from 2007 (EC Directive 2002/51/EC). COPERT 3 and 4 (Computer programme to calculate emissions from road transport) models are widely used to calculate both regulated and unregulated emissions of motorcycles. However, all these are based on fixed legislative driving standards, not on the local driving conditions (Gkatzoflias et al., 2007).

The harmonised world motorcycle emissions certification/test procedure (WMTC) was developed by collecting driving behaviour data of motorcycles from different locations in Europe, Japan, Germany, China, and the US with the aim of developing global technical regulations (GTR) for harmonised motorcycle emission test cycles [GTR (2), 2005]. After their introduction in 2007, emission standards have been periodically revised. In the UK, the TRL work and the Design Manual for Road and Bridge (DMRB) reports are used to estimate pollution loads from motorcycles. In addition, some efforts have been made to refine these to reflect local conditions and effects of different levels of traffic control on emissions (Saleh et al., 1998; Booth et al., 2001 and Kumar et al., 2007). A major limitation of much of the above work is that emission factors have been calculated based on average speed patterns and not on real-world driving conditions. Therefore, they do not embrace actual motorcycle driving behaviour in any particular urban area and hence not suitable to be used by agencies controlling local air pollution.

Hence, in this research the Edinburgh Motorbike Driving Cycle (EMDC) has been calibrated to represent local driving conditions. Measurement of instantaneous speed, acceleration, deceleration, and distance travelled and route tracking data were undertaken to develop the driving cycle for each of the urban and rural modes.

Traditionally, emissions are measured on dynamometer tests using representative driving cycles in order to meet regulatory pre-production and assembly line emissions requirements. These results do not lend themselves to real-world applicability since (1) they are performed on new, well-tuned models and (2) the standardised testing does not mimic today's driving styles (Joumard et al., 1995; Sjodin and Lenner, 1995). Nevertheless, the availability of this data has led to widespread use of these laboratory results to predict real-world pollutant levels in many countries.

Recent field studies of actual emissions via tunnel studies (Pierson et al., 1990; McLaren et al., 1996), roadside point sampling, across-the-road remote sensing (Zhang et al., 1996) and instrumented vehicles (Kelly, 1993; Guenther et al., 1996) have noted the inadequacies of using laboratory data to estimate real-world pollutant levels. These inadequacies are generally attributed to factors such as the limitations of the test driving cycle, vehicle tampering, poor vehicle maintenance and the high frequency of 'off-cycle' driving events under actual driving conditions (Black, 1991).

Hence, in this research onboard emission measurements from motorcycles driven in the city of Edinburgh and laboratory emission measurement in both urban and rural area of Edinburgh motorcycle driving, have been undertaken.

A number of modelling software tools are available to model the impacts of different transport scenarios, in particular micro-simulation tools. However, one major drawback of such tools is that most of them have some inbuilt parameters which are calibrated for certain traffic conditions and do not necessarily reflect the local traffic conditions in any city. As a result, traffic flows, delays and queues and consequently transport emissions will therefore be questionable.

In this research, a micro-simulation model (VISSIM) for motorcycle driving cycle has been calibrated for a traffic corridor in Edinburgh, in which the driving cycle characteristics as well as measured local traffic conditions were considered.

Moreover, one of the possible tools of assessing impacts of different driving conditions on emissions is to use different emission measurements approaches in local driving conditions. To the knowledge of the author, there have not been many studies, which analysed and compared the results from laboratory measurements, real-world and emissions calculations from micro-simulation modelling.

In this research, the final part of the analysis presents evaluation and comparisons of real-world emission measurements, emissions obtained from a laboratory under EMDC, WMTC, and ECE driving conditions, onboard and those from a micro-simulation model.

2.2.1 Selection of the case study

It should be mentioned here that, from the review of the available literature, it appears that although a number of studies in Europe (e.g. France, Greece and the UK) and Asia (e.g. Taiwan, Bangkok and Hong Kong) investigated the car and motorcycle driving cycle (e.g. Andre and Pronello, 1997; Samaras and Ntziachristos, 1998; Tong et al., 1999; Leong et al., 2002; Tzirakis et al., 2006; Andre et. al, 2006; Vasic and Weilman, 2006, Hung et al., 2007) very few studies in the UK investigated the car driving cycle; the only two reported works on car driving cycle are from Southampton and Edinburgh (see Samuel et. al., 2002 and Booth, 2001). Moreover, no study, which investigated driving cycle for motorcycles in the UK has been reported.

Therefore, Edinburgh has been selected as a case study to carry out the investigation. It should be noted here that Edinburgh has been previously used as a case study for the investigation of private car and bus driving cycle (EDC) for the city (Booth, 2001) only on an urban corridor using car-chasing techniques. In their work they found that the driving cycle for cars in Edinburgh is characterised by an average speed 20 km hr^{-1}, time spent in acceleration 31% and deceleration 29%. Their study was limited to the urban corridor and to the car/ bus vehicle type (i.e. no consideration of motorcycle). Moreover, the lack of further studies on driving cycles in Edinburgh since that study makes a good case for carrying out this current research. The current study therefore investigates motorcycle-driving cycle for both urban and rural corridors in Edinburgh using GPS technology. The results of both studies have been compared in the thesis.

2.3 Aim and objectives

The main aim of this study is to calibrate real world driving cycles for motorcycles in Edinburgh and to investigate their impacts on emissions. To achieve this aim, the following objectives have been set up:

1. To carry out a literature review on driving cycles for different motor vehicles, motorcycle emissions and standard methods of emission measurements, and micro-simulation modelling.
2. To develop the driving cycle for motorcycles in Edinburgh for each of the urban and rural modes. This requires measurement of instantaneous speed, acceleration, deceleration, distance travelled, and route tracking data.
3. To carry out onboard and laboratory emission measurements using motorcycles. Onboard data measurements of data include CO, HC, NO_X, lambda measurement, onboard speed and acceleration measurement. The laboratory measurements include CO, HC, and NO_X emission measurement on different driving cycles (ECE, WMTC, EMDC urban and rural).
4. To simulate the real-world driving cycle using VISSIM and estimate emissions for a suitable traffic corridor in Edinburgh.
5. To validate and compare the emissions obtained from real-world, laboratory and micro-simulation measurements.
6. To discuss, analyse the results, conclude the work and recommend for future research.

2.4 Research approach

To achieve the above aim and objectives, the overall approach agreed for the research is illustrated under the following tasks (see Figure 2.1).

1. Calibration and validation of a real-world motorcycle driving cycle in Edinburgh (EMDC).
2. Emission estimation: Applications of the derived EMDC using the following approaches to estimate emissions
    a. Onboard measurements
    b. Emission estimations in laboratory
    c. Using micro-simulation methods
3. Analysis of results, comparisons and evaluations

Each of these tasks is briefly discussed in the following sections:

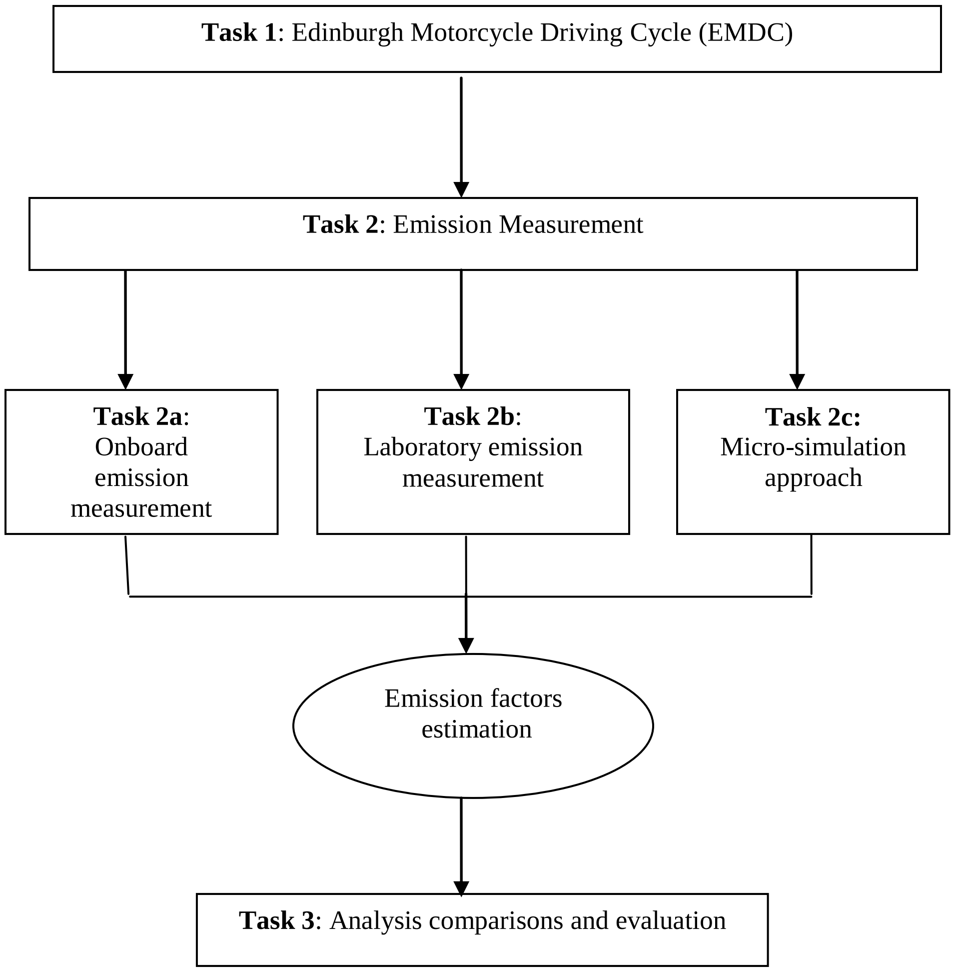


Figure 2.1 Research approach flow diagram

Task 1: Calibration and validation of a real-world Edinburgh motorcycles driving cycle (EMDC)

To derive the driving cycle, the following methodology has been used (Figure 2.2)

- Select a number of urban and rural routes in Edinburgh city and its surroundings
- Instrumentation of motorcycles and recruitment of a number of volunteers to ride along the selected routes
- Data collection

- Calibrate and validate Edinburgh Motorcycle Driving Cycle (EMDC) for both urban and rural driving conditions

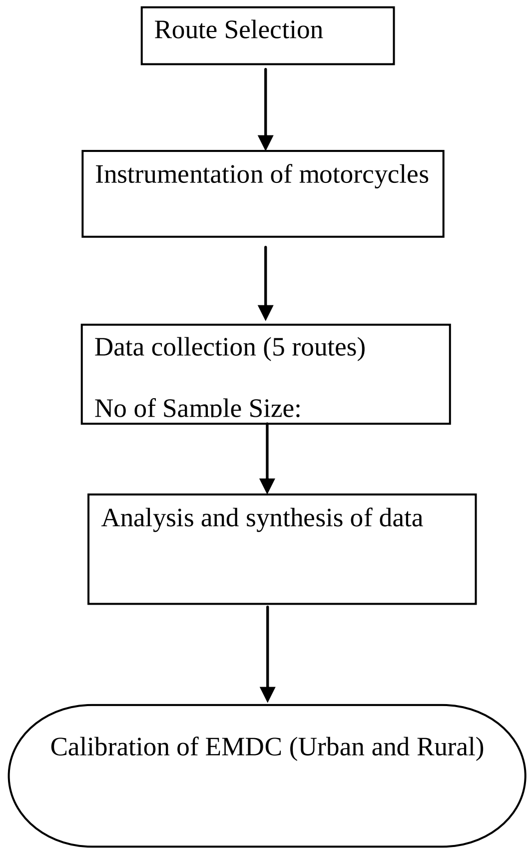


Figure 2.2 Task 1 EMDC flow diagram

It should be noted that emission measurements were not undertaken during the derivation of the driving cycle because no equipment was available at that stage. Therefore, calibration of EMDC took place first before applying this driving cycle in emission measurement in the three different approaches.

Task 2: Application of the derived EMDC using three approaches to estimate emissions

As an application of the emission measurement approaches under EMDC, a traffic corridor, the air quality monitoring area (AQMA) in Edinburgh, has been identified. The following emission measurement approaches have been used. The flow diagram for onboard, laboratory and micro-simulation approach and their respective data set, samples and discussed subsection are shown in the Figures 2.3 (a, b & c) and 2.4 (a, b & c) respectively.

a. On board experiment

The flow diagram of the onboard emission measurement is presented in Figure 2.3a. Two different motorcycles were driven along the selected corridor and onboard measurements of speeds, acceleration and emissions were recorded for driving conditions in Edinburgh city centre to represent the EMDC conditions. Estimates of fuel consumptions were made to calculate the overall emissions along the test corridor. Data obtained from the installed equipment (GPS-based Performance Box-PB and Probike Microgas Analyser-PMGA) were synchronized using a subroutine programme in Excel. The total emissions were classified into different driving modes (deceleration, acceleration, cruise, and idling) to get the modal emission. The modal emission estimates for CO, HC and NO_X were made; hence the emission factors were determined. Finally, impacts of speed on emissions of CO, HC and NO_X were analysed.

b. Laboratory measurement

Using laboratory equipment to measure emissions based on the calibrated EMDC (urban and rural) and the comparisons of these emissions with other driving cycles (including the WMTC and the ECE) are presented in this section. The emission measurement flow diagram is shown in Figure 2.3 b.

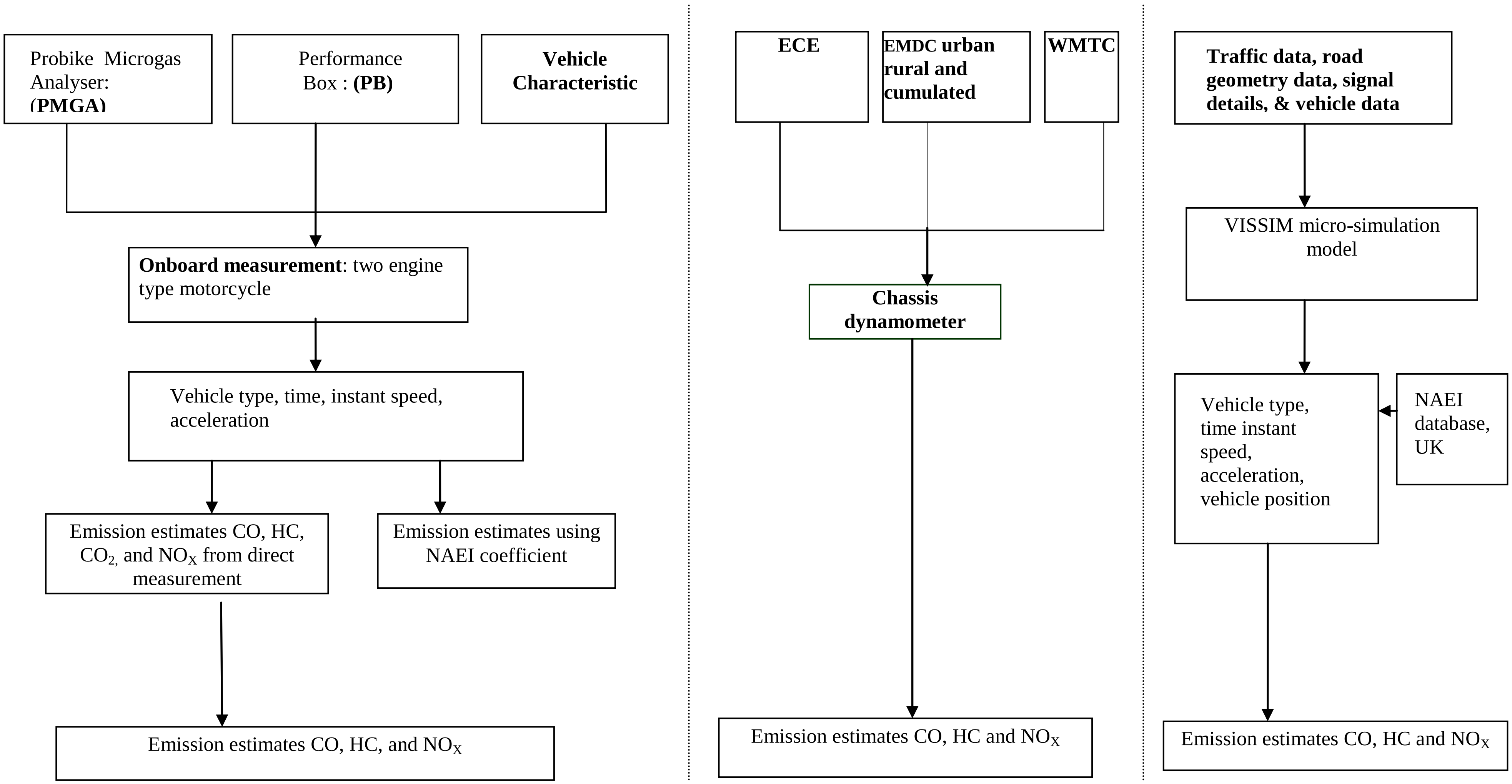


Figure 2.3 a–Onboard emission **Figure 2.3 b-Laboratory measurement** **Figure 2.3 c- Micro-simulation**

Figure 2.3 Task 2 Emission measurement flow diagram

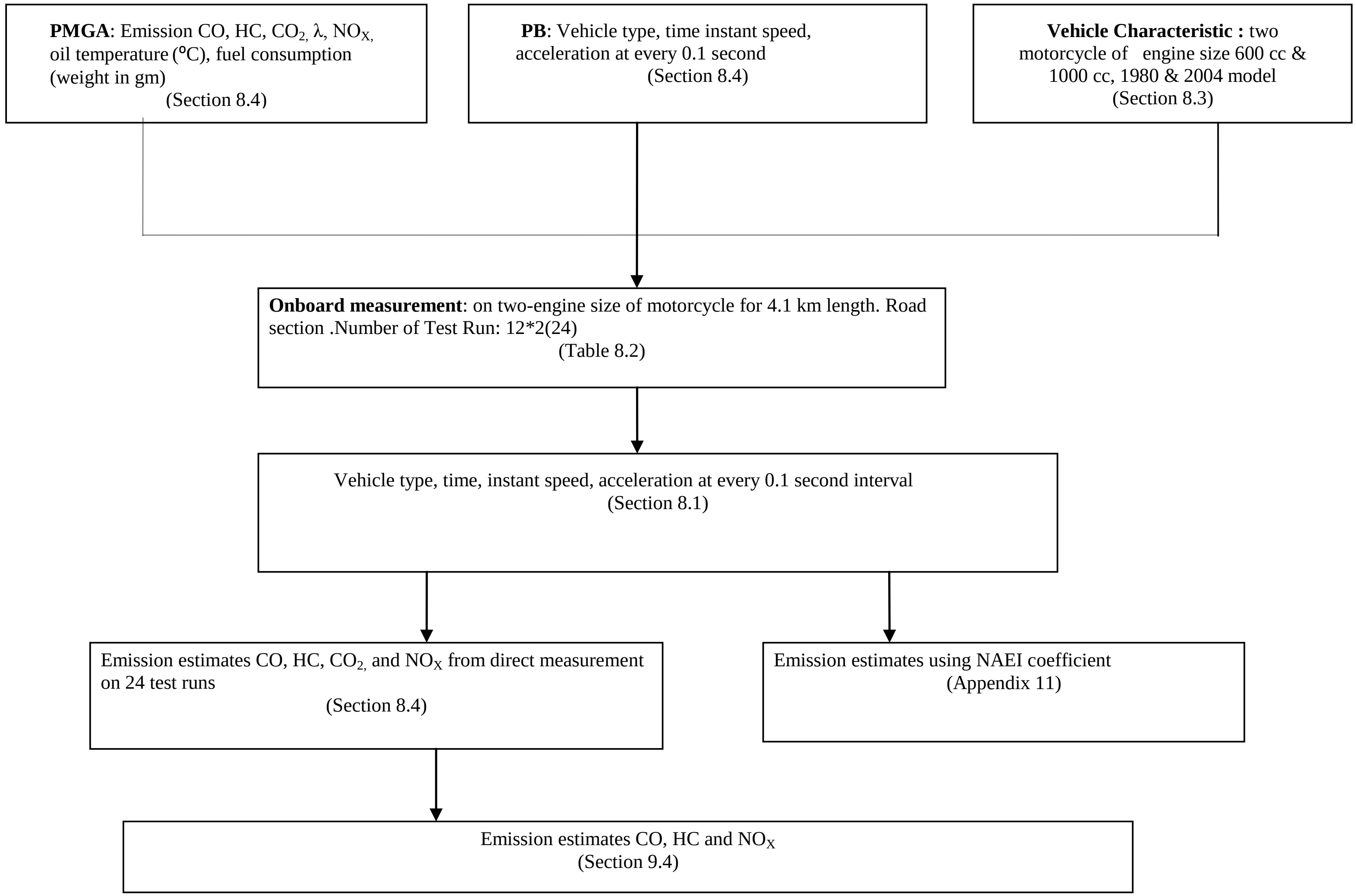


Figure 2.4 a- Data set, samples and related subsection for Onboard emission

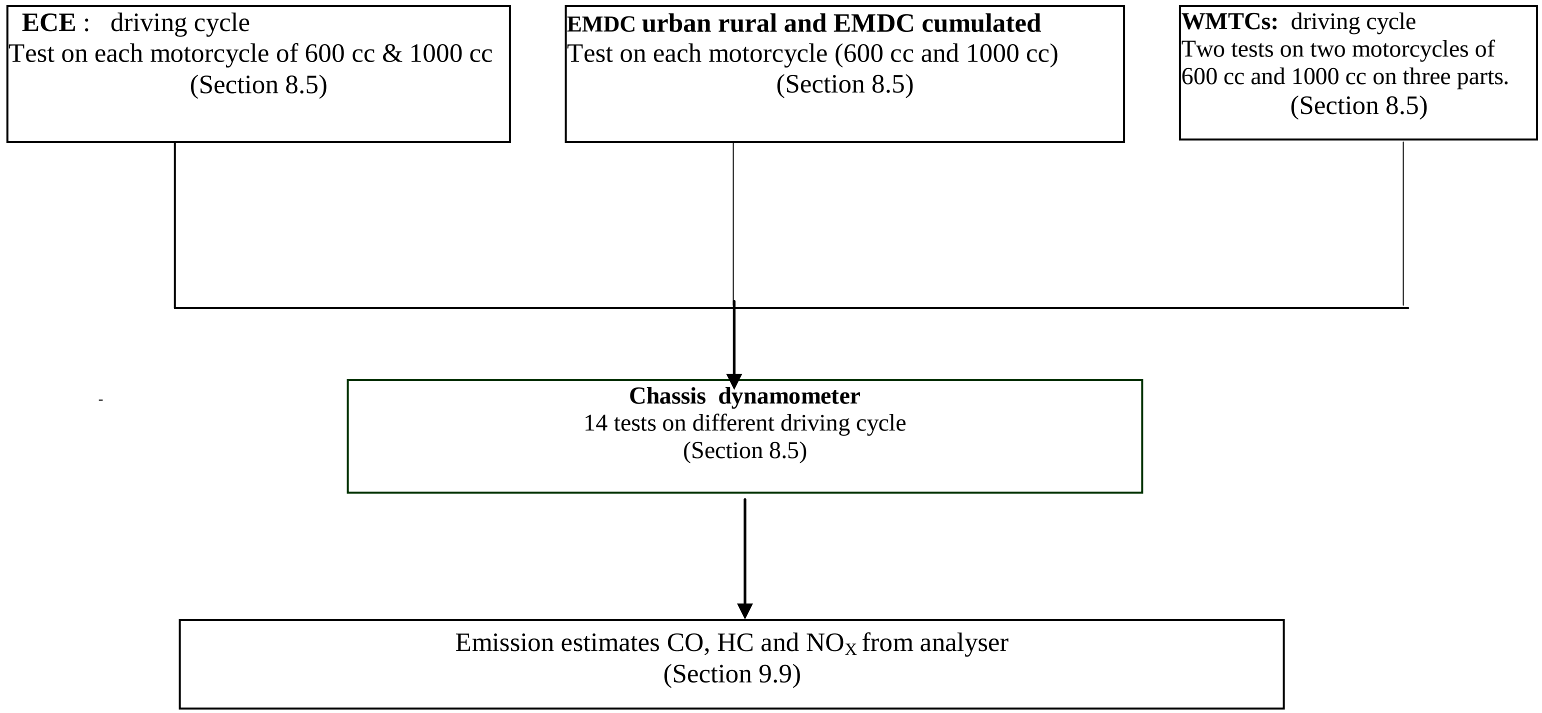


Figure 2.4 b- Data set, samples and related subsection for laboratory measurement

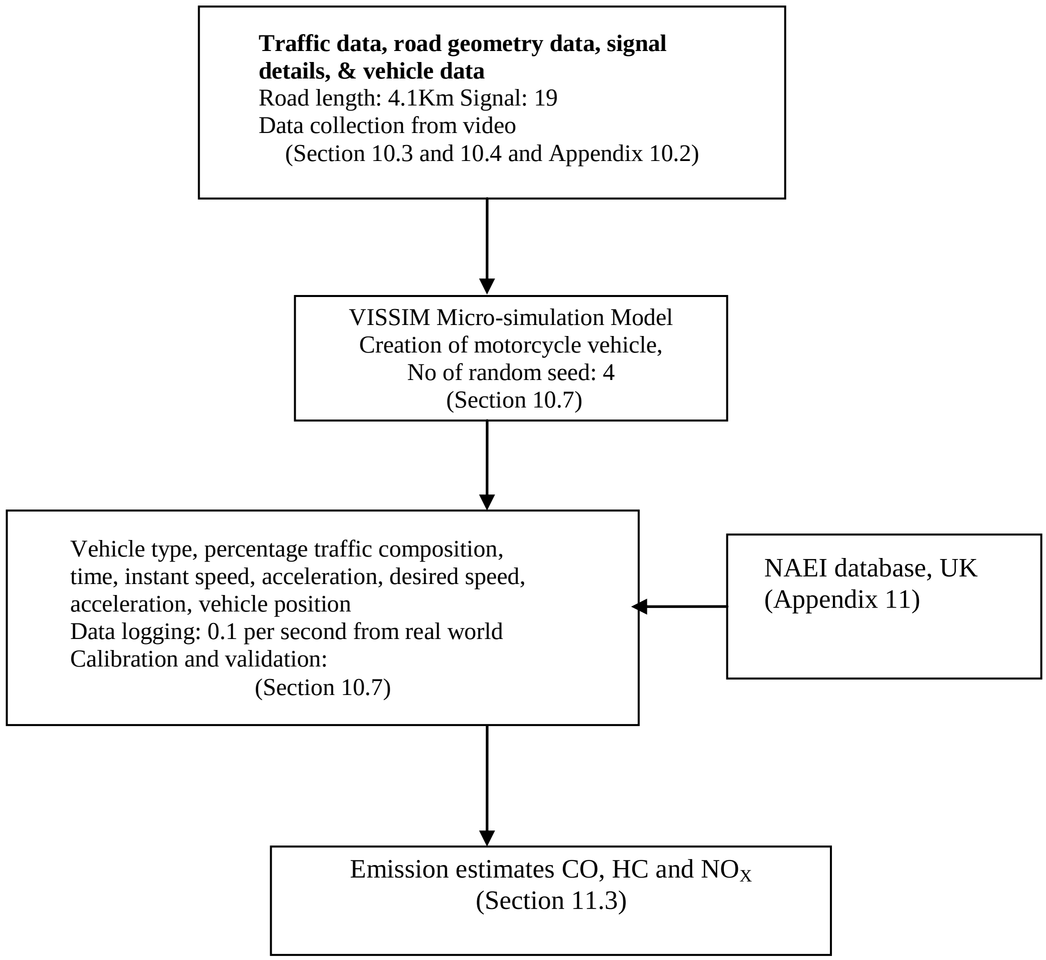


Figure 2.4 c- Data set, samples and related subsection for Micro-simulation

c. Micro-simulation approach

The VISSIM micro-simulation has been used to model driving cycle along the selected traffic corridor. For this modelling exercise, the motorcycle has been created as a vehicle type in VISSIM with all its characteristics. These include dimensions, speed, composition in traffic, acceleration, deceleration, lateral and longitudinal manoeuvres, as well as other driving behaviour characteristics. Other traffic conditions such as signal cycle and traffic information were also recorded using video. Figure 2.3c shows the structure of modelling motorcycle driving along the selected corridor and emission estimation using VISSIM.

A number of runs of VISSIM were undertaken until stabilisations were achieved. Then a number of runs with a number of random seeds were analysed and before the outputs were produced. Calibration and validation of the model were assessed using the GEH statistics. The motorcycle driving cycle and its characteristics were obtained from VISSIM. Emissions were calculated externally using these characteristics as well as emission factors obtained from the National Atmospheric Emission Inventory (NAEI). It should be noted here that the other alternative to this approach was to use an external emission module (ENVIRO PRO) from PTV suite of models, but the emission factors of that model were very out of date and not applicable in the UK.

Task 3: Analysis, comparisons and evaluations

In this task, the evaluation criteria for the assessment of different emission factors were setup and the results were compared with different driving cycles, engine types, and measurement approaches. For evaluation of approaches, evaluation criteria were set up based on regulatory emission standards for motorcycles (three stages, Euro 1, Euro 2 and Euro 3, and WMTC). These are the standard regulations and are important to compare the results against this.

2.5 Limitations of the research

2.5.1 *Limitations of the Edinburgh motorcycle driving cycle research*

1) Classifications of driving cycle and associated factors (e.g. urban/rural, time of day, speed, engine size, and driver characteristics) and number of experimental or lab tests were limited. For example, Andre (1997) classified 12 types of driving conditions, such as congested urban (high stop duration, low steady speed), free flow urban (unsteady speed), secondary roads (unsteady speed), main roads (unsteady speed), and motorway (unsteady speed). Many studies considered a larger number of classifications. Driving cycles in our study were only classified as urban or rural due to the frequently used routes of drivers in Edinburgh and due to limited time, number of routes and drivers.
2) Number of routes, number of motorcycles and number of runs per motorcycle (weekdays) considered in this investigation were limited to five due to limitations of time, budget and number of volunteers. Time of run was also limited to AM peak and PM off-peak to avoid the delay in rush hours. Because of distribution patterns of motorcycle engine size, the most of the engine sizes selected were greater than 600 cc.
3) Very little data for weekends was available due to unavailability of volunteers; and therefore there was no further investigation of impacts of weekdays on driving cycle and emissions.
4) Due to security of equipment and reliability of data, most of the volunteer were chosen from the University staff; therefore, the work place destination was limited to one.
5) Delhi motorcycle driving data was collected with a single type of motorcycle due to safety and time limitations.

2.5.2 *Limitations of emission measurement using Edinburgh motorcycle driving cycle and onboard emission measurement*

1) Although a high level of data disaggregation was achieved, (e.g. data from the gas analyser has been analysed for 2-second intervals) in principle, further refinement of

the data was possible. However, because of the incompatibility between the outputs from the Performance Box at 1 second and the gas analyser the approximation of results for 2-second interval data was used in the analysis.

2) A crude estimation of fuel was made in the absence of a fuel meter. This was because of legislation enforcement regarding installing equipment or tampering with the engine.
3) There might be errors in emission measurements as a result of the analyser going off-line due to its limited logging period (60 minutes of PMGA) and the synchronisation issues with data logging in the PMGA and PB which had impacts on the accuracy of the results
4) Only two sizes of engines (600 cc and 1000 cc) were used for onboard measurement.
5) A limited number of dynamometer tests have been conducted because of time and fund limitations. Although the sample sizes of the dynamometer tests were smaller than those used for test runs in the development of driving cycles in real world, the current results could be generally used for motorcycle emission behaviour under actual driving conditions in Edinburgh.

2.5.3 Limitations of the emission estimation using Micro-simulation approach for Edinburgh motorcycle driving cycle research

1) Number of runs, amount of variations in input parameters and combinations of different variables was limited to a manageable number due to constraints of time and limitation of licence period.
2) Engine size classes, change of traffic flow in AM/PM peak, change of signal cycle time in AM/PM off-peak and peak (daily variations) were limited due to restriction of time and licence of VISSIM 5.10 (for extended network), which was supplied for a limited time period.
3) Chosen corridor for micro-simulation were limited to only the corridor used for the onboard emission measurement.

4) Some of the data collected from Edinburgh City Council were old, but this was the only source of data available. However signal data and traffic data were collected from video filming
5) More discussion of research limitations and any assumptions made are described in Chapter 11 (see Section 11.2.5).

2.6 Structure of thesis

The thesis report is structured in thirteen chapters as follows. Chapter 1 presents a background and an introduction to the study. Motivations of research, aim and objectives, research approach, and limitations of the study are discussed in Chapter 2. The literature reviews on driving cycle, emission measurement, and micro-simulation research have been presented in three chapters (Chapters 3, 4 & 5). Chapter 6 presents the methodology to develop the Edinburgh motorcycle driving cycle and its results are discussed in Chapter 7. Chapters 8 and 9 present the methodology for and the results of measurement of emissions using onboard and laboratory tests. The methodology for developing driving cycles using micro-simulation models (VISSIM) is discussed in Chapter 10, while Chapter 11 presents the data analysis using micro-simulation. The results from the different investigations are discussed and compared in Chapter 12. Finally, Chapter 13 concludes the research work and provides recommendations for further research.

CHAPTER 3 REVIEW OF LITERATURES ON DRIVING CYCLE

3.1 Introduction

Existing tools and methods for evaluating pollutant emissions from road transport are based on knowledge of specific vehicle emissions, which are usually measured on a test bench/chassis dynamometer using driving cycles or speed against time curves. The representation and descriptive quality of these cycles are thus of prime interest for the assessment of pollutant emissions and their evolution in an appropriate manner. In Europe, motorcycle emission legislation was produced in 1990. Current legislative driving cycles for motorcycles are the European Driving Cycle (Euro 1 in 1999, Euro 2 in 2003, Euro 3 in 2006 and the World Motorcycle Test Cycle (WMTC) driving cycle in 2006). However, their representations for local pollution control are still limited due to their uniform and steady driving cycle and lack of representation of local vehicle-based driving data. Numerous studies have been conducted to build up driving cycles in different contexts and demonstrate their strong influence on pollutant emissions (Watson, 1995; Joumard et al., 2000; Andre et al., 2006; Booth et al., 2001 and Hung, et. al., 2007). In Britain, the cost of an emission test on a single vehicle could be around £10,000 (Booth et al., 2001). Therefore, most often a unique set of driving cycles is used, independent of vehicle characteristics, which may be perceived as a weakness in terms of representation. In reality, the different types of vehicles are driven in different manners, and should therefore be tested according to their performance levels and uses.

The effects of different traffic management schemes on air quality can be assessed by estimating the driving cycle before and after improvement of different traffic management measures. Driving cycle can also be used for traffic demand management for effective signal control and controlling the congestion across the streets by altering the driver characteristics through enforcement and route control.

Most of the research on driving cycles was undertaken for private cars in Europe. Because, emission legislations for cars was introduced in the early 80s and regulatory emission standards for motorcycles were introduced in 1990 therefore, a big gap in emission standards for motorcycle and car remained. Moreover, less research work was done on the motorcycle driving cycle and its emissions as compared to cars in Europe. This chapter reviews the latest and most relevant work on the development of the driving cycle for motorcycles, cars, and other types of vehicle (i.e. Light Goods Vehicle (LGV) / Heavy Goods Vehicle (HGV), tricycle, electrically driven vehicle) inside and outside the UK. This review of method and assessment parameters is used in developing the driving cycle for motorcycles in Edinburgh (more details are discussed in Chapters 6, 7 and 12).

3.2 Review of European regulatory emission legislations for motorcycles and mopeds

3.2.1 Economic commission of Europe driving cycle (ECE)

European Union (EU) has target for transport hydrocarbon emissions, which is not to exceed 13.7% of the total from all sources by 2010. Motorcycle/two-wheeler traffic would still account for two to three percent of total traffic volume by that date. Motorcycle and moped emission legislations were evolved as per United Nation Economic Commission of Europe (UN-ECE) regulations 40 (motorcycles) and 47 (mopeds) in 1990. This was followed by the so-called ‘multi directive’ 97/24/EC, which introduced stringent emission limits for mopeds and motorcycles (classified as two engine sizes of 150 cc or more) as based on the test cycles of UN-ECE regulations 40 and 47 (EC Directive 97/24/EC, 1997). For 4-stroke engines, the 2003 stage represents a reduction of about 60% in the emission for carbon monoxide and hydrocarbons over the emission limits adopted in 1999, while these reductions were 30% and 70% in the case of 2-stroke engines. The present limit for oxides of nitrogen, a component of smog, remained unchanged for 2003 to allow industry more time to concentrate on achieving the other targets. The adopted ECE 40 driving cycle was less dynamic than the actual driving behaviour, and did not take into account the warming-up stage of motorcycles (Greening, 2001).

Therefore, a new directive was implemented and new standards adopted for motorcycles and mopeds were not considered in the Directive 97/24/EC. The new standards were implemented in two phases, and no distinction was made between two- and four-stroke engines (EC Directive 2002/51/EC). The new requirement included the adoption of first part the urban driving cycle (UDC) which is similar as ECE15 and second part the extra urban driving cycle (EUDC) (Figure 3.1). The ECE15 test cycle simulates a 4.052 km urban trip at an average speed of 18.7 km h^{-1} and at a maximum speed of 50 km h^{-1} with duration of 780 seconds. The EUDC cycle shows more aggressive, high-speed driving characteristics with a maximum speed of 120 km h^{-1}. Its duration is 400 seconds over 6.955 km at an average speed of 62.6 km h^{-1}. Since the year 2000, the 40-second idle period at the beginning of the European driving cycle (EC Directive, 2000) was omitted. Thus, the emissions during the cold start are included in the driving cycle and this makes EC 2000 a more realistic test procedure since 2006.

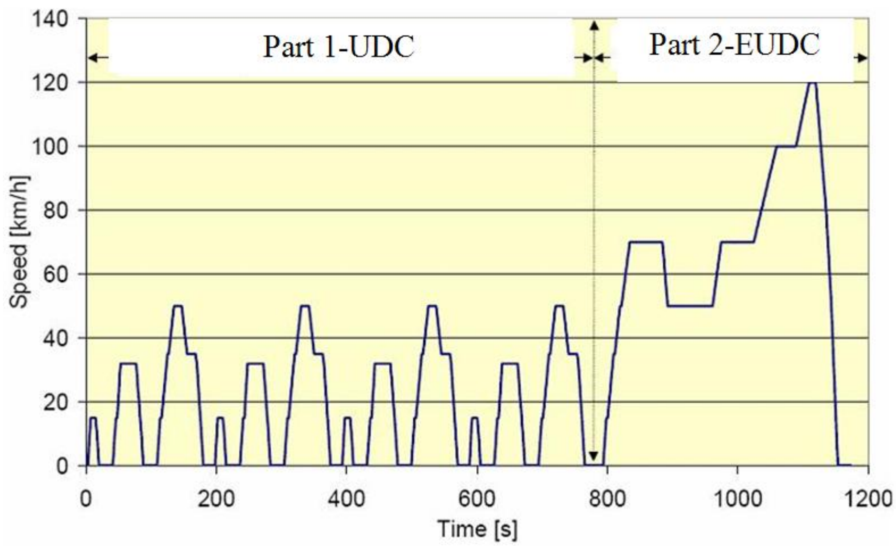


Figure 3.1 Euro driving cycle

The Euro driving cycle had uniform speed and acceleration, and therefore does not represent real-world driving behaviour; also, it does not represent the driving characteristics of motorcycles certainly not at a local level. However, it was applied to emission testing of cars and motorcycle manufacturers for emission test certifications.

3.2.2 *Worldwide real-world motorcycle driving cycle for emission certification (WMTC)*

Because of worldwide increase in ownership and use of motorcycles, it has become more important to focus on motorcycle emissions and to tighten emissions limits. A new test for worldwide motorcycle emissions certification (WMTC) cycle was proposed since 2006. A driving cycle specially for motorcycles was developed by the WMTC group (Figure 3.2) to develop a standard worldwide real-world driving cycle for emission certification for motorcycles and a Global Technical Regulation (GTR) on the certification of motorcycles. The WMTC group was formed from members of the following countries/organisations:

1. Association for Emissions Control by Catalyst (AECC)
2. European Commission
3. Germany
4. International Motorcycle Manufacturer Association (IMMA)
5. Japan
6. Netherlands
7. Spain
8. Switzerland
9. UK
10. USA

This driving cycle consists of three phases: urban, rural and motorways. The driving data for motorcycles were collected from China, Paris, Pisa, USA and Japan over the period 1990 - 2000.

The WMTC is a three-phase transient cycle (with an ambient temperature start), and is more representative of actual on-road driving conditions. This cycle was developed with the aim to replace various existing legislative cycles for two-wheelers (e.g. the ECE) with a standard worldwide real-world driving cycle.

The approach adopted to develop this driving cycle was based on speed distribution (> 60 km h^{-1}, between 60 and 90 km h^{-1} and > 90 km h^{-1}) and the driving cycle consists of 3 part. Finally, for each part the share of speeds was calculated below 60 km h^{-1}, between 60 and 90 km h^{-1} and above 90 km h^{-1}. Subsequently the allocation was used to develop three part of driving cycle [GTR (2), 2005].

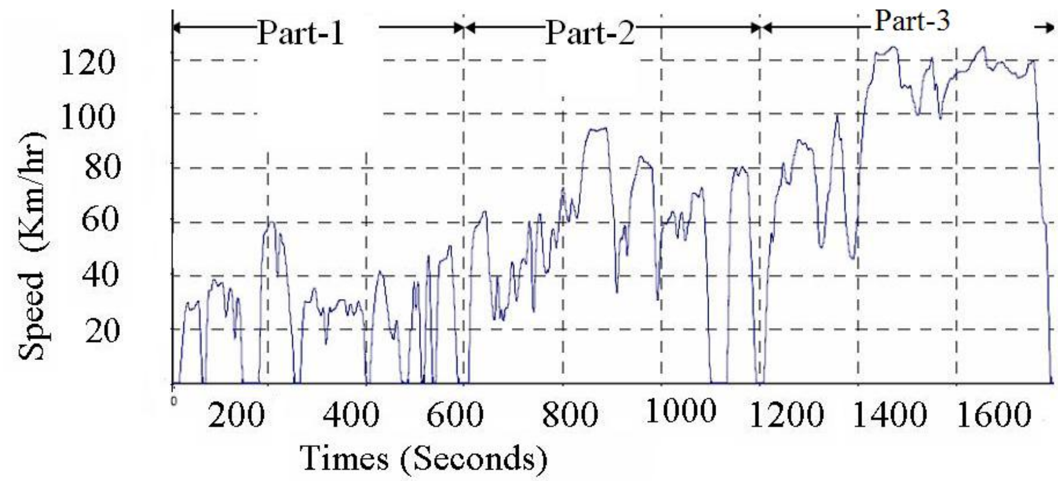


Figure 3.2 World motorcycle test cycle (WMTC)

While the driving cycle takes into account the characteristics of speed, the data is collected for a range of cities all over the world (Paris, Piza, China, and US) and therefore does not reflect the local driving conditions in any areas of Edinburgh.

3.3 Review of previous work on driving cycle

3.3.1 Motorcycle driving cycles

In the late 1950s in Los Angeles, the first attempt was made to characterise driving patterns from within vehicles for better understanding of urban automobile emissions. Several on-road driving cycles for four-wheelers had been developed to meet local road and traffic conditions in order to estimate automotive emissions and fuel consumption both locally and regionally (e.g. Kent et al., 1978; Lyons et al., 1986; Andre and Pronello, 1997; Ergreneman et al., 1997; Tong et al., 1999). However, driving cycle studies for motorcycles are still uncommon. This might be because motorcycles require careful analysis as they have different driving speeds and different driving behaviour and lane use, which are quite different from that of cars (Kumar et al., 2007).

The first research on motorcycle driving cycle was done in Taiwan in 1997. Tzeng and Chen (1998) developed the Taipei Motorcycle Driving Cycle (TMDC) for emission and fuel economy and compared the driving characteristic with FTP 75 (US), and the ECE (European Driving Cycle). In another study, Tsai et al., (2000) investigated the emissions of carbon monoxide (CO), nitrogen oxide (NO_X) and total hydrocarbon (THC) from seven new and 12 in-use motorcycles with or without catalyst testing using a dynamometer. Leong et al., (2002) adopted the Bangkok Driving Cycle (BDC) for motorcycles using the ECE. Chen et al., (2003) developed the representative driving cycles for motorcycles using the principle of least total variance in Taiwan. The motorcycle driving cycle investigation was done on 125, 90 and 50 cc engine size motorcycles. They used eleven criteria to the characterise the driving cycle (Table 3.1). The TMDC was found of high average acceleration, deceleration, high acceleration-deceleration changes and low average travel speed (Figure 3.3). Sixteen 4-strokes and 29, 2-stroke engines were tested on a chassis dynamometer using the TMDC and ECE-40 cycle. In these tests, emissions from the TMDC were observed to be higher than those tested by ECE regardless of 4-stroke or 2-stroke technology. The fuel economy of 2-stroke engines tested under TMDC was found to be lower than the ECE driving cycle. However, fuel economy of the 4-stroke engine motorcycle tested with the TMDC was higher than the 2-stroke motorcycles. The CO and HC emission of 2-stroke motorcycles were higher than 4-stroke engine motorcycles, while NO_X emission of 2-stroke motorcycles was lower than 4-stroke engine motorcycles regardless of whether they were tested on TMDC or ECE.

Table 3.1 Assessment parameters to describe characteristic of driving cycle for motorcycle

Sr. No	Assessment Parameters
1.	Travel time
2.	Travel distance
3.	Average running speed (idle excluded)
4.	Average acceleration of all acceleration phase (a > 0.1 ms^{-2}),
5.	Average deceleration of all deceleration phase (d > 0.1 ms^{-2}),
6.	Mean length of driving period (from starting to idling)
7.	Average number of acceleration–deceleration changes (& vice versa) within one driving period
8.	Percentage of idling time (V < 3 km hr^{-1}, a<=0.1 $ms^{-2,}$, d<=0.1 ms^{-2})
9.	Percentage of acceleration time (a > 0.1 ms^{-2})
10.	Time percentage of constant speed (a <=0.1 $ms^{-2,}$, d <=0.1 ms^{-2})
11.	Percentage of deceleration time (d >0.1 ms^{-2})

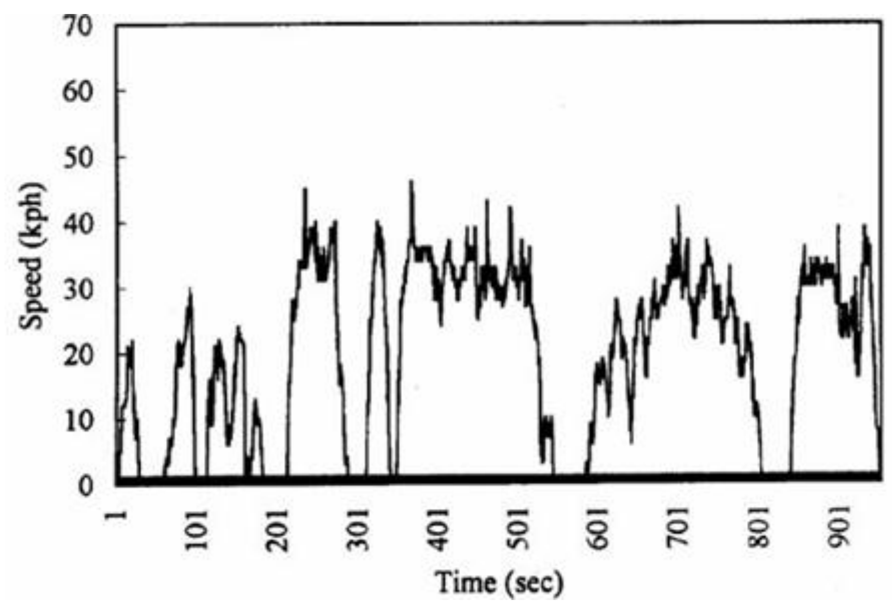


Figure 3.3 Taipei motorcycle driving cycle

Chen et al., (2003) investigated motorcycle-driving cycle to estimate real world emissions and fuel consumption in urban and rural driving conditions in Taiwan (Figure 3.4). Twenty-four crossroads were selected in the three urban cities (i.e. eight in Taipei (commercial and residential sites), twelve in Taichung (downtown and suburban sites) and four in Kaohsiung (commercial and industrial sites)). Most crossroads in the cities were on the arteries with some of them on the major roads in suburban areas of Taichung City. In addition, 15 crossroads were selected in the Pingtung County, including major and secondary roads (all were paved roads).

Motorcycle-to-motorcycle follow-up method was adopted to establish the on-road driving cycles with an instrumented motorcycle. The surveyors randomly selected a passing driver (target) and followed the target to their destinations. Successful follow-ups of duration of at least 660 s (or 11 min) to 15-20 min were formed to avoid short driving patterns.

P-values at significance levels of 0.01 and 0.05 using the *Z*-test were used to characterise parameters in three urban and one rural cycle (Devore, 1991). The representative driving cycle in a region was based on the sampled trips with the least total variance.

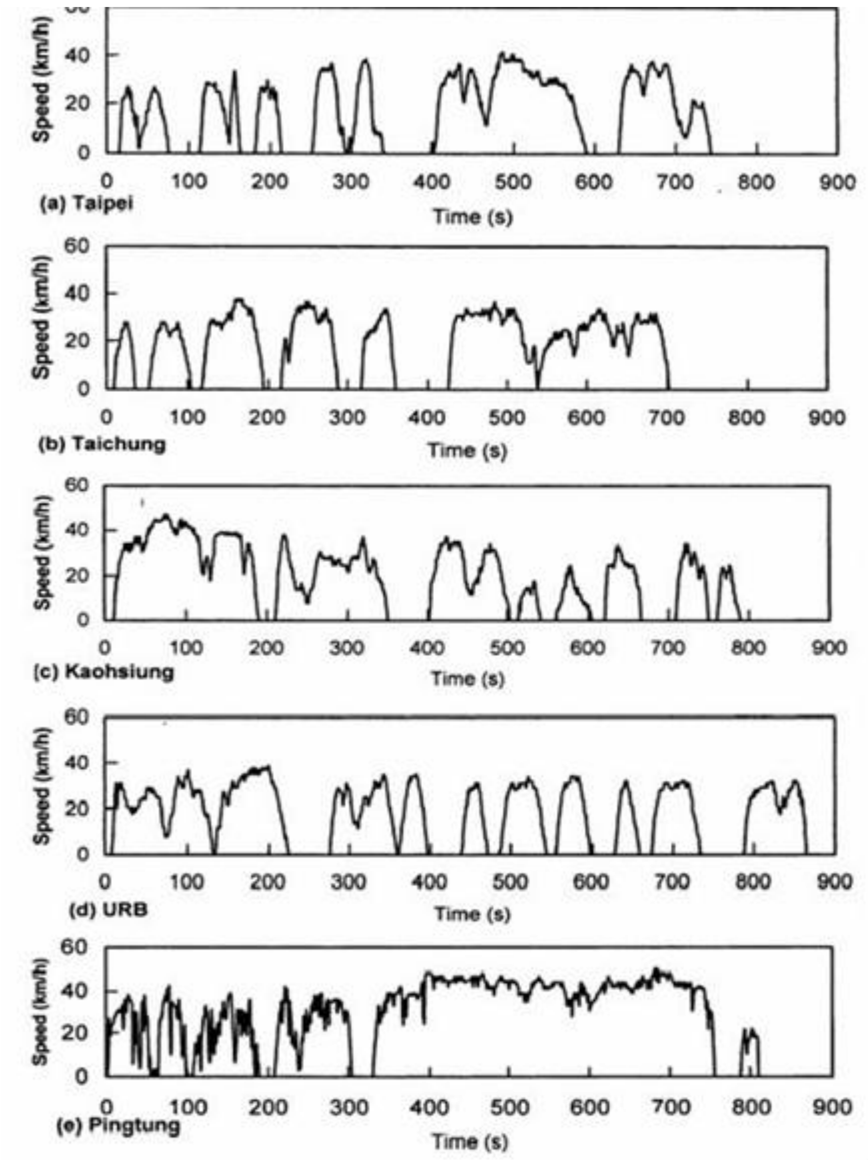


Figure 3.4 Representative of road driving cycles for (a) Taipei city, (b) Taichung city, (c) Kaohsiung city, (d) URB and (e) Pingtung county

Leong et al., (2002) developed the Bangkok Driving Cycle (BDC) for motorcycles. This driving cycle was adapted from Approval and Conformity of Production Emission Standards for motorcycles (First Level) of Bangkok, which adopted the ECE Regulation 40. A chassis dynamometer was used to simulate the average driving patterns, based on traffic conditions and street configuration in the Bangkok metropolitan area.

The BDC was made up of three micro-trips based on cold, hot and warm start in addition to hot soak period as presented in Figure 3.5 to represent of driving conditions in the central area of the city. The first micro-trip was called a 'cold start' and lasts for 676 seconds allowing the engine to reach its normal operating temperature at the end of this stage micro-trip. The second micro-trip was called 'hot running' and lasts for 619 seconds, the final micro-trip was a 'warm start' and lasts for 658 seconds. Average driving speed of the BDC was 24.6 km h^{-1} (excluding the 25 min 'hot soak' between 1295 and 2795 s, when the engine was shut off for various reason). The total travelling distance was equivalent to 13.4 km. Cruising, acceleration and deceleration were represented by trace speeds, which can be interpreted by intermittent peaks in the driving cycle.

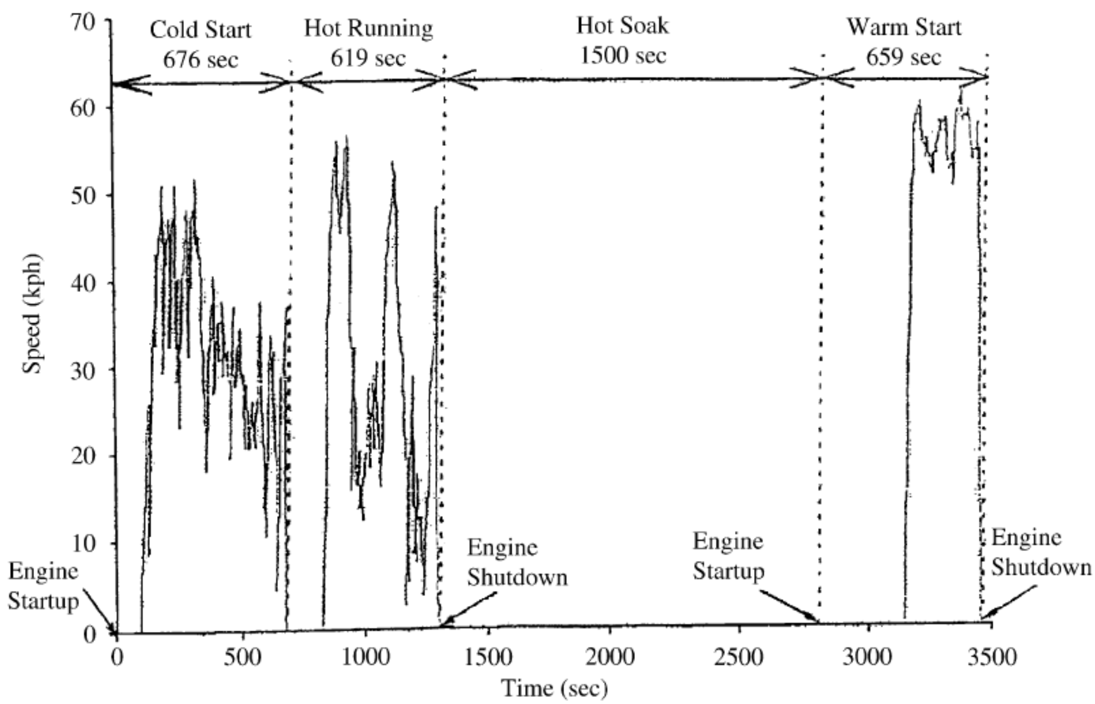


Figure 3.5 Bangkok driving cycle

Tsai et al., (2005) developed a driving cycle for the motorcycle of Kaohsiung city (KHM). The characteristics of this driving cycle were compared with ECE and FTP-75. The mean length (about 111 s) of the KHM cycle was much higher than those of other two cycles (45–77 s). The number of acceleration–decelerations within one driving period of the KHM cycle

(16.4) was also higher than that of other cycles, except for the Taipei motorcycle driving cycle (TMDC). This demonstrates that there was a high frequency of speed variations in motorcycle driving in the Kaohsiung metropolitan area. The KHM cycle also had a much lower percentage of cruising time (8.7%) than the other driving cycles. The reason for the frequent speed variation was that the driver had to change speed to adapt to the road traffic conditions. Significant differences were observed in the KHM speed and idle time compared with the WMTC. Therefore, the WMTC was not suitable for use in the investigation of motorcycle emission in Kaohsiung metropolitan area. ECE and KHM speed diagrams with respect to time in the representative driving cycle (KHM 32) are presented in Figure 3.6 for comparison. The ECE cycle is a regulated driving cycle and displays a smooth driving cycle. In contrast, the KHM cycle displayed random driving conditions. The speed of the KHM cycle was also slightly higher than that of the ECE cycle. As for the idle stage, there were 11 stages in the ECE cycle, yet only 6 stages in the KHM cycle for the same time duration (up to 800 s). Therefore, replacement of the ECE cycle was inevitable in emission testing in order to reflect local traffic conditions and driver behaviour.

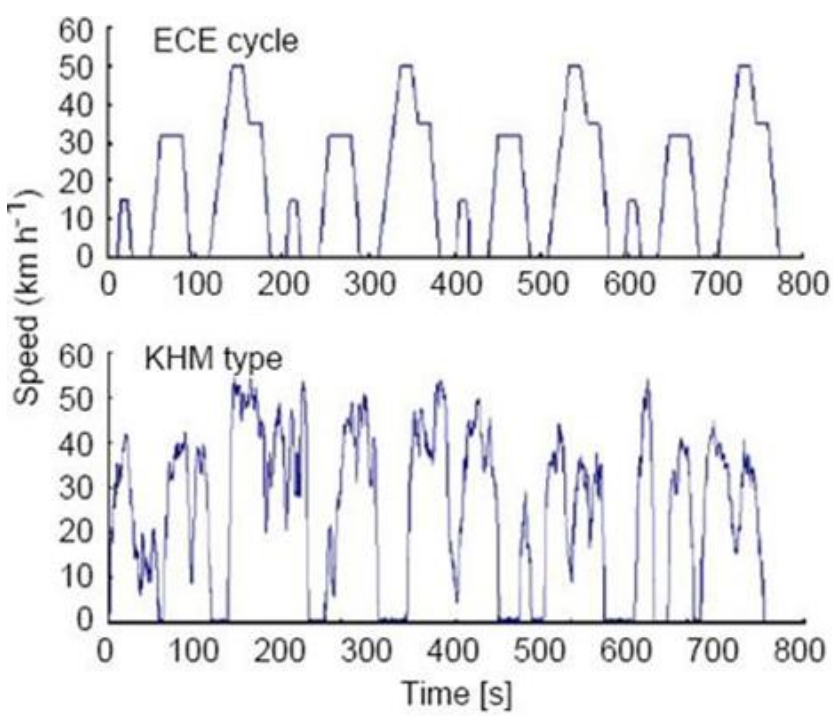


Figure 3.6 Driving cycle of Kaohsiung and ECE driving cycles

Biel University of Applied Science, Switzerland developed a real-world motorcycle-driving pattern to reflect driving in and around the Swiss town (Figure 3.7). This driving cycle was established for motorcycles and two-wheelers in Swiss circumstances by the Fachhochschule Biel (FHB). These circumstances comprised of urban, suburban and country road riding (at that time the motorway section had to be omitted because of cooling problems in the chassis dynamometer) (Vasic and Weilman, 2005). The 'centre' pattern represents inner city driving and combined with the 'periphery' pattern and it models urban driving behaviour as presented in Figure 3.7.

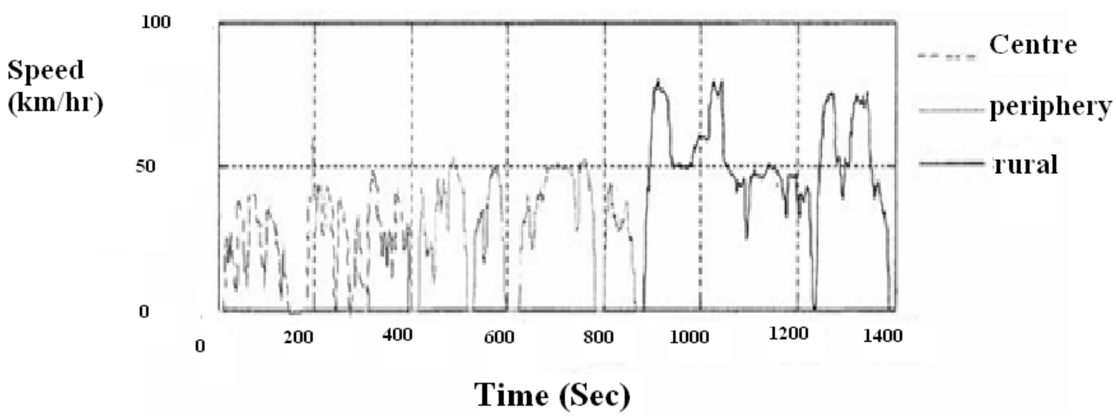


Figure 3.7 Fachhochschule Biel cycle established by the Biel laboratory

3.3.2 Review of driving cycles for cars

Several investigations of driving cycles were carried out to meet the local and national demand for estimation of fuel consumption and emissions. Kulher and Karsten (1978) developed Improved European driving cycle based on the data collected on number of routes in European cities using on-board measurement and several assessment parameters. In the early 1990s, strict emission standards were introduced by the EU. The emission performances of these cars were tested using the ECE driving cycle. Test procedure were proposed, which made it possible to reproduce one or several short and reproducible tests, and its significant parameters related to fuel consumptions in the UK. The cycles were generated by random simulation of speed and time curves, as a function of the distributions (probability densities) of the various modes and transitions including gear changes. In another study in Turkey, Ergeneman et al., (1997) developed a methodology to generate a driving cycle from measured data for different vehicle groups, such as private cars, taxis, buses, and minibus, for various regions in the city possessing similar characteristics and developed a mathematical approach representing similar driving conditions to predict exhaust emissions and fuel consumptions. For emission inventory in the UK, emission factor was developed by the Highways Agency in the UK, which has been detailed in the DMRB to provide guidance for the calculation of emissions generated by road traffic (Cloke et al., 1998). Andre et al., (2004) derived urban driving cycles based on the actual car use and operating characteristics to measure emission based on kinematics sequence methodology for European traffic condition. The following sections discusses in details the driving cycle for cars in different cities.

(a) Edinburgh driving cycle (EDC)

In the UK, the Edinburgh driving cycle (EDC) was developed by using the car-chasing technique on six routes in Edinburgh city (Booth et al., 2001). The typical EDC is presented in Figure 3.8. The EDC urban cycle does not include the motorway. In the EDC 60% of the time was spent in acceleration and deceleration modes where as in the ECE one third of the total time was spent in acceleration and deceleration. The reason for this discrepancy is that the EDC is the real representation of traffic in EDC, while the ECE is a synthetic cycle, which uses simplified modes (Andre, 1996).

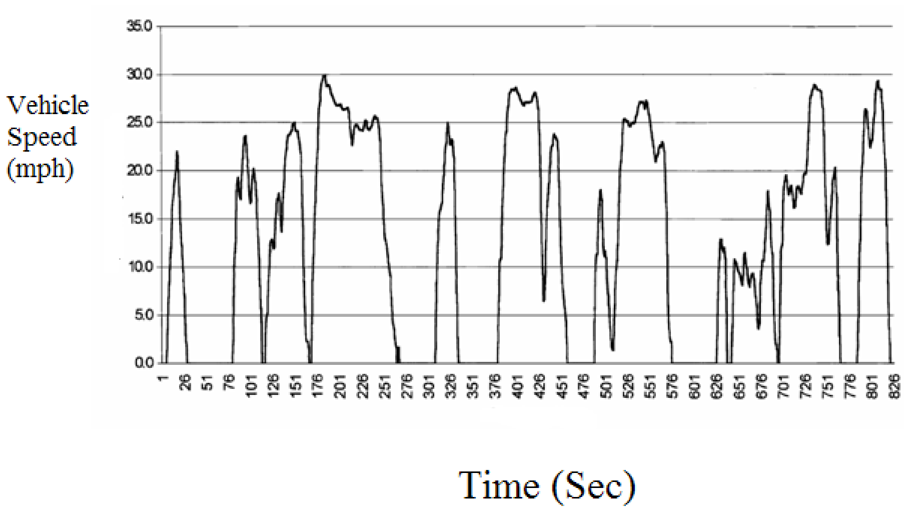


Figure 3.8 Edinburgh driving cycle

The 1027 data sets were collected using an instrumented vehicle with on-board data logger reading and storing data every second. The data was recorded for two months, from Monday to Sunday in the first phase and two weeks in the second phase on six different routes with desired driving instructions. The data was analysed using computer and statistical analysis techniques. A new methodology called TRAFIX (Traffic Flow Index) was developed to calculate the representative driving cycle from the 1027 data sets.

(b) Common ARTEMIS driving cycle (CADC)

The Common ARTEMIS driving cycle (CADC) was developed within the European research project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). This driving cycle represents the European driving behaviour for passenger cars. The CADC consists of three parts, each representing an aggregated road category: urban, road (i.e. extra-urban) and highway. All three parts can be used independently, because all start and end with zero speed (Andre et al., 2004; Vasic and Weilemann, 2006). Figure 3.9 shows the driving cycle in three different categories of roads (urban, rural and motorway).

Andre et al., (2006) investigated the driving cycle for specially designed high and low power cars — which differ in their driving conditions, characteristics of driving conditions and vehicle usage — as a function of vehicle categories (e.g in weight, power, etc.). The influence of different test cycles for different vehicle types was assessed. The development of real-world driving cycles was carried out as: (i) observation of vehicle uses and operating conditions (ii) analysis of driving conditions (iii) vehicle trips (iv) development of representative driving cycles. Those steps produced driving cycle micro- trip structure and characteristics as well as driving conditions. Actual driving conditions of the high and low power car (both on motorway and urban) were derived using statistical tests (Figures 3.10, 3.11**)**. In addition, emission measurements on 30 representative cars of French fleets were carried out to develop the emission standard.

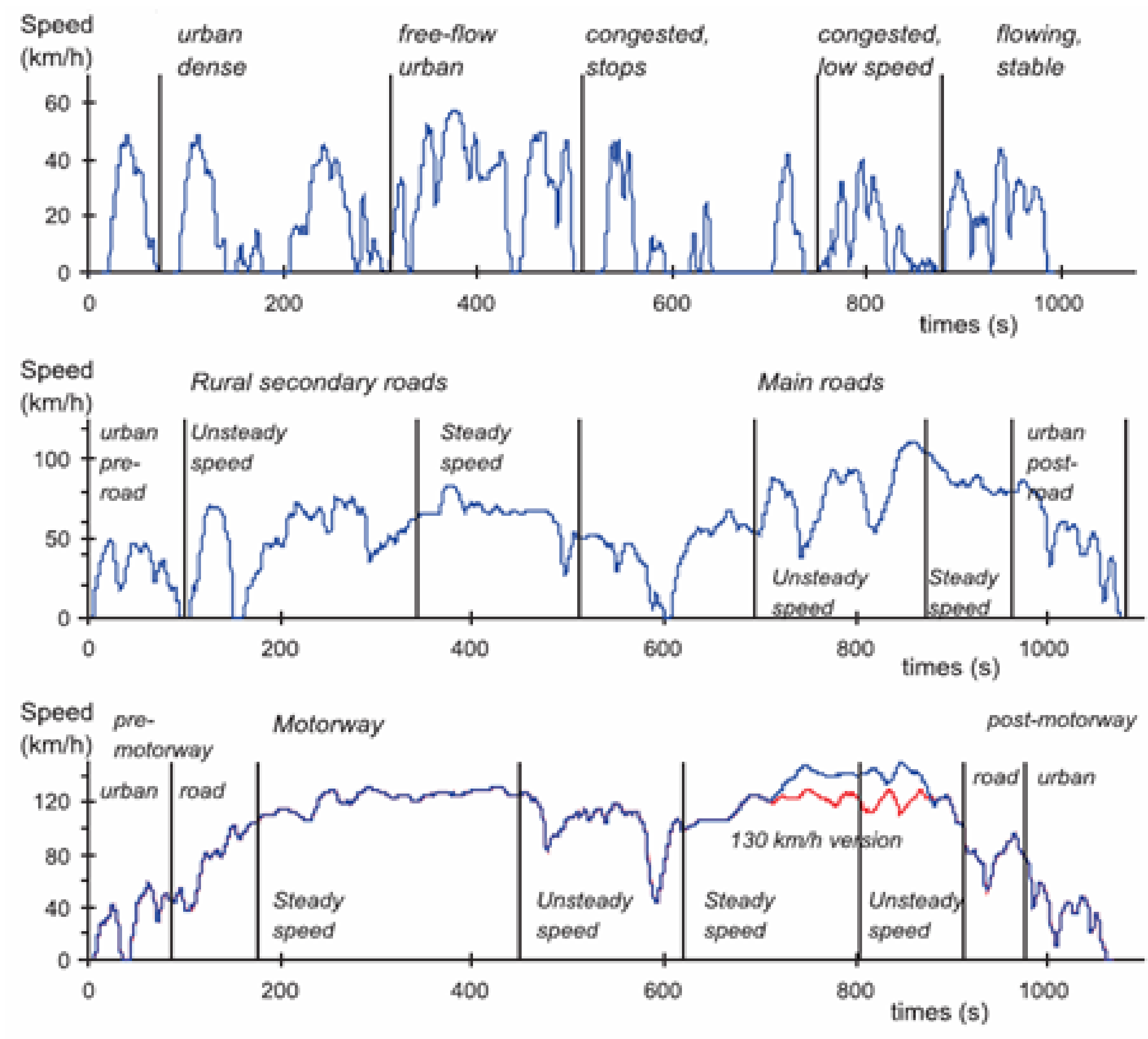


Figure 3.9 ARTEMIS urban, rural-road and motorway driving cycles

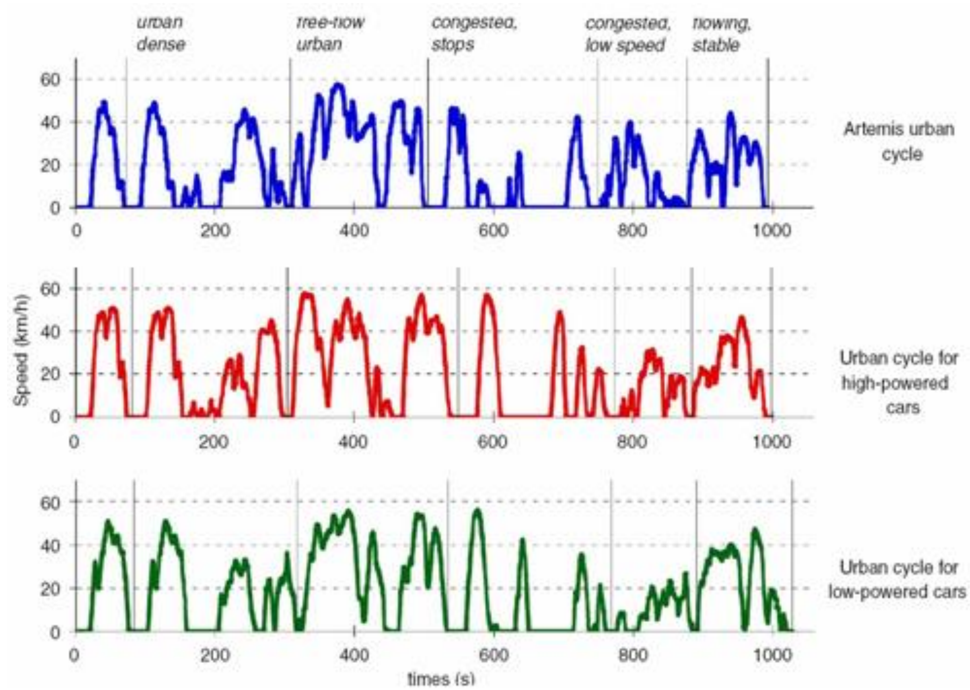


Figure 3.10 ARTEMIS driving cycle for high and low-powered cars

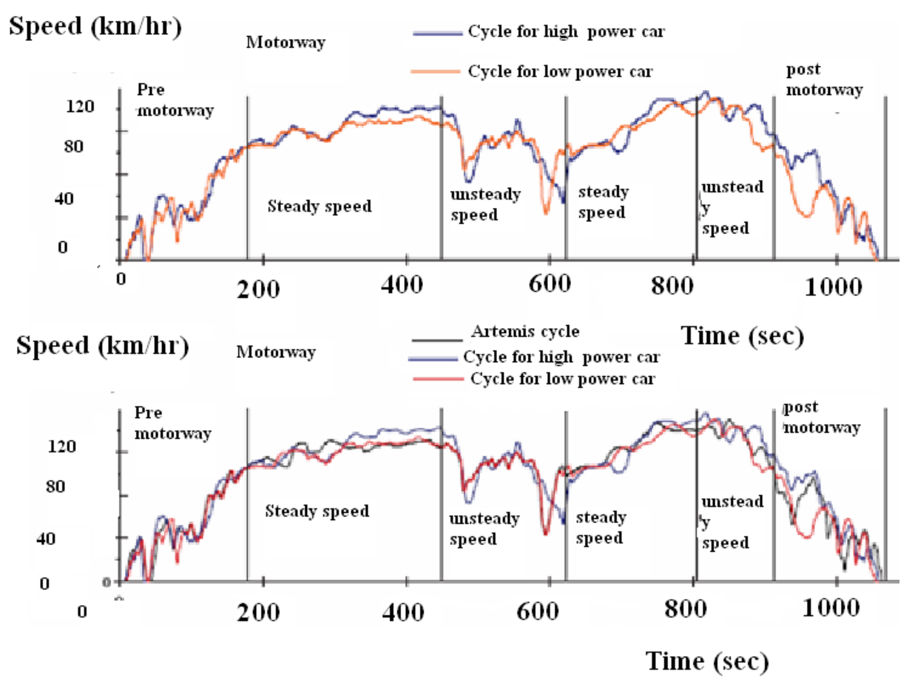


Figure 3.11 Motorway driving cycle for high and low powered cars and ARTEMIS cycle

(c) Athens driving cycle (ADC)

Tzirakis et al., (2006) developed the Athens driving cycle (ADC) for cars in 2002 (see Figure 3.12). Driving data was collected from the area of the Attica basin for seven days using chase car methods. The test cars, of different engine capacity, were equipped with a GPS receiver, an accelerometer an OBD (On-Board Diagnosis reader) and the information recording and synchronizing was done using a laptop computer. Collected data were statistically processed using specially developed software taking into account parameters such as the topographical characteristics of the Attica basin (i.e. road slope). Fuel consumption observation showed an increase for ADC compared to the ECE depending mainly on the vehicle. Exhaust emissions were found to be higher in the ADC (0% to 300%) with a few exceptions for HC and CO measured on PT Cruiser type of vehicles. This might be partly because no data from any Greek city was used in the European driving cycle (ECE).

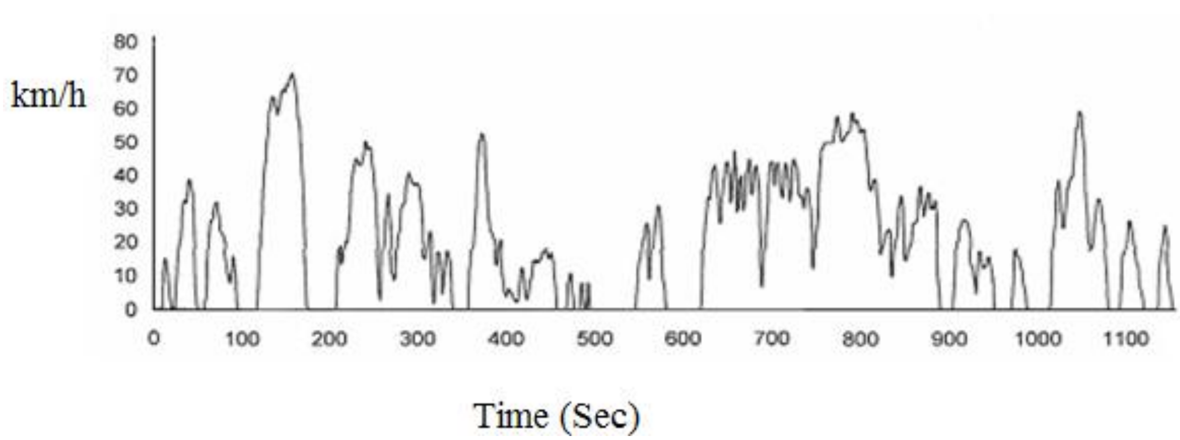


Figure 3.12 Athens driving cycle using actual traffic data in the year 2002

(d) Sydney driving cycle

In Australia, Kent et al., (1978) developed the driving cycle for Sydney. The data were collected using an instrumented vehicle, which was driven over the selected routes during the morning traffic peak (6:30 - 9:15 am) during weekdays. The joint relative frequency of speed and acceleration for the total Sydney data showed a very smooth distribution of acceleration and deceleration over 0-32 km h^{-1} speeds. Dominant cruising speeds were around 40-64 km h^{-1}, with very little time at speeds in excess of 72 km h^{-1}.

Dominant cruise modes occurred at 32.4 km h^{-1} and there were significant contributions at speeds around 80 and 88 km h^{-1}. A driving segment consists of a portion of the speed-time trace from any of the data bounded by an idling mode at either end and usually of about two minute's duration. Numerous segments were selected and the traces were first visually inspected for any abnormal characteristics. The average speed, percentage idle time and root mean square acceleration together with the predicted emissions were calculated for each segment. The cycle shown in Figure 3.13 was developed by making up the characteristics of the representative cycle.

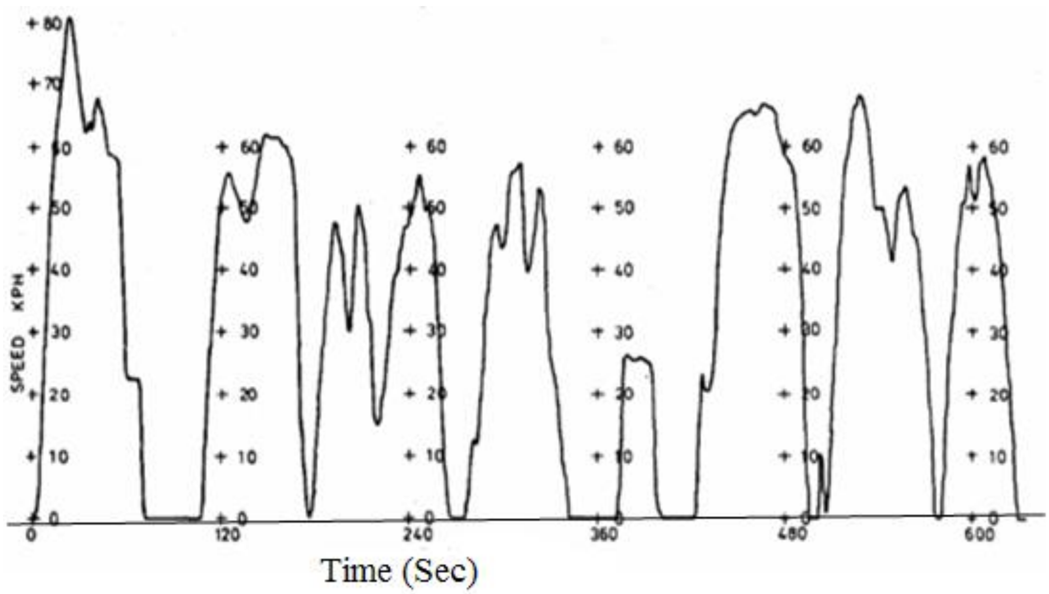


Figure 3.13 Speed-time plot of cycle synthesised for Sydney conditions

(e) Perth driving cycle

They used two data collection methods: random chasing of drivers and the manual data logging. In the random chasing of drivers within each area, the chase car technique, in which drivers follow vehicles at random anywhere within each area, was used. Moreover, in the manual data logging, the summary of all trips were logged manually (e.g. average speed, RMS, acceleration, number of stop and percentage idle time) to provide a large amount of data on a variety of trips throughout Perth. In some cases, the trips were recorded on cassette tape for detailed analysis and comparison to other results.

Results of data collected on the Perth driving patterns indicated that the difference in driving patterns was observed as the distance from the Central Business District (CBD) increased (i.e. in terms of average speed and related factors). Average speed was found to be above 40.0 km h^{-1}, which incorporated less than one stop per km and less than 15% of idling time. The fitting of air conditioning resulted in a fuel penalty of 14.9%. In another study, Kenworthy et al., (1983) derived the driving cycle for Perth city. The data were collected using the instrumented vehicles, which also recorded the fuel monitoring and speed measurement,

In another study for the same city, Lyons et al., (1986) produced a representative driving cycle for an urban area based on dynamic driving data collected through the chase car techniques using the urban data collected in Perth. The simulation procedure were based on a 'Knight's Tour' concept which relies on the understanding of the dynamics of urban driving, in particular the observed tendency to maintain constant acceleration and deceleration rates.

(f) Melbourne driving cycle

Watson et al., (1982) developed the driving cycle of Melbourne. The purpose of the cycle was to provide the basis for a more realistic assessment of the emissions and fuel consumptions for Melbourne driving conditions. The cycle was based on Melbourne morning peak driving patterns.

(g) Delhi driving cycle

Gandhi et al., (1983) studied the driving pattern using an instrumented car of 1000 cm^3 engine capacity, which formed a major share of the vehicles population in Delhi/New Delhi area along four representative routes. The car was used to record fuel consumption, trip length, trace of speed and change of speed with time, and time spent in various speed blocks.

(h) Federal test procedure (FTP)

The Federal test procedure (FTP) cycle is shown in Figure 3.14. It illustrates real driving times and conditions by measuring the speed of a vehicle as a function of time.

The FTP test cycle simulates the 17.7 kilometres (11.4 miles) of a driving cycle through Los Angeles at an average speed of 34.1 km h^{-1} (corresponding to 21.2 miles per hour). The test measures the emissions of CO, HC and NO_X, and involves a cold start after an engine idle period for eight hours, a hot start, and a combination of urban and highway conditions. The emissions of CO and HC and catalyst light-off values were much smaller in the case of the FTP cycle. The FTP test cycle was a transient test cycle with a highly dynamic nature; therefore, it is better suited for emissions during real driving, where the temperature of exhaust gases increases gradually (Laurikko, 1994).

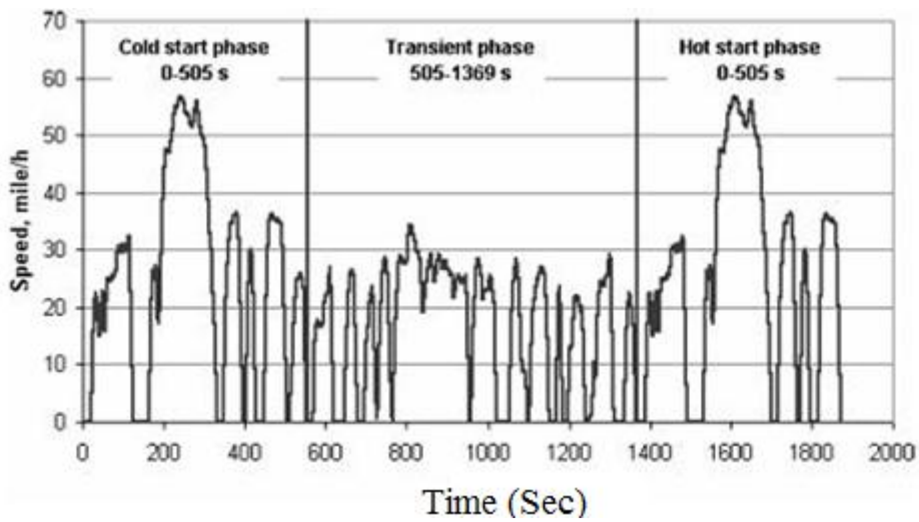


Figure 3.14 FTP-75 test driving cycle established by the EPA

(i) Hong Kong driving cycle

Tong et al., (1999) developed a standard driving cycle in the urban areas of Hong Kong. The typical driving cycle is presented in Figure 3.15. On-road speed-time data were collected by an instrumented diesel vehicle along two fixed routes located in two urban districts in Hong Kong. An on-board measurement method was adopted in and the test vehicle was a Toyota Hiace manual transmission diesel van with an engine capacity of 2799 cm^3. In developing the standard driving cycle for Hong Kong, nine parameters were calculated from onboard survey data. Twenty short driving periods, each bound by idle times, were selected from the data. Ten such cycles were developed and the best cycle was finally selected with minimum total percentage error. The synthesized standard driving cycle revealed that Hong Kong had more idle, acceleration and deceleration times and rarely reached the cruising mode.

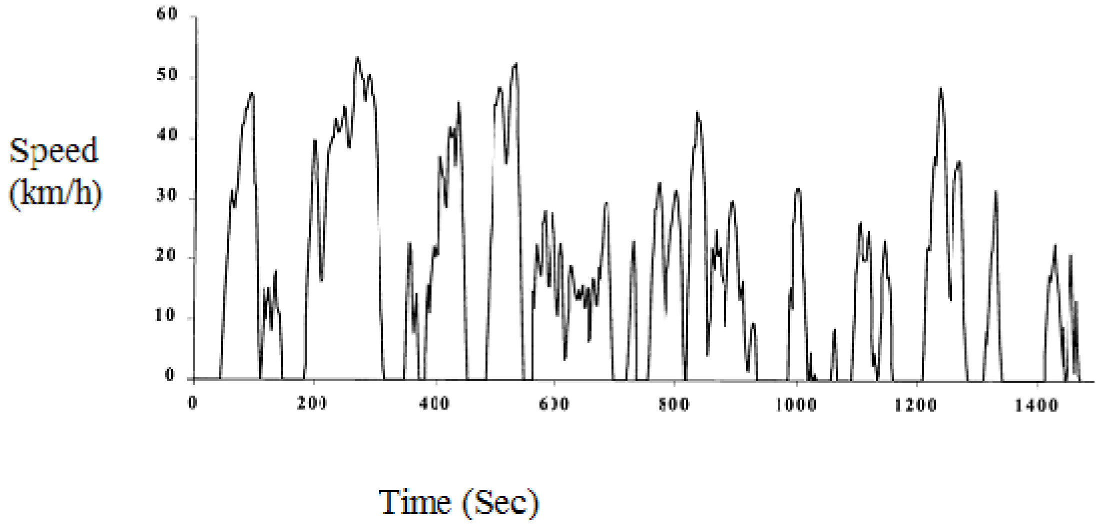


Figure 3.15 Synthesised driving cycle for Hong Kong

In the same city, Hung et al., (2007) developed three driving cycles for three traffic conditions (urban, sub-urban and highway driving behaviours, see (Figure 3.16)). Both car-chasing and on-board measurements techniques were employed. A total of 29 hours of data were collected with the car-chasing technique along nine selected representative routes during the morning peak hours. The representative routes were defined by the combination of road sections, forming a typical commuting route, with the highest overall Average Annual Daily Traffic (AADT). Hung et al., (2007) adopted 13 set of assessment criteria adopted in developing the Hong Kong driving cycle.

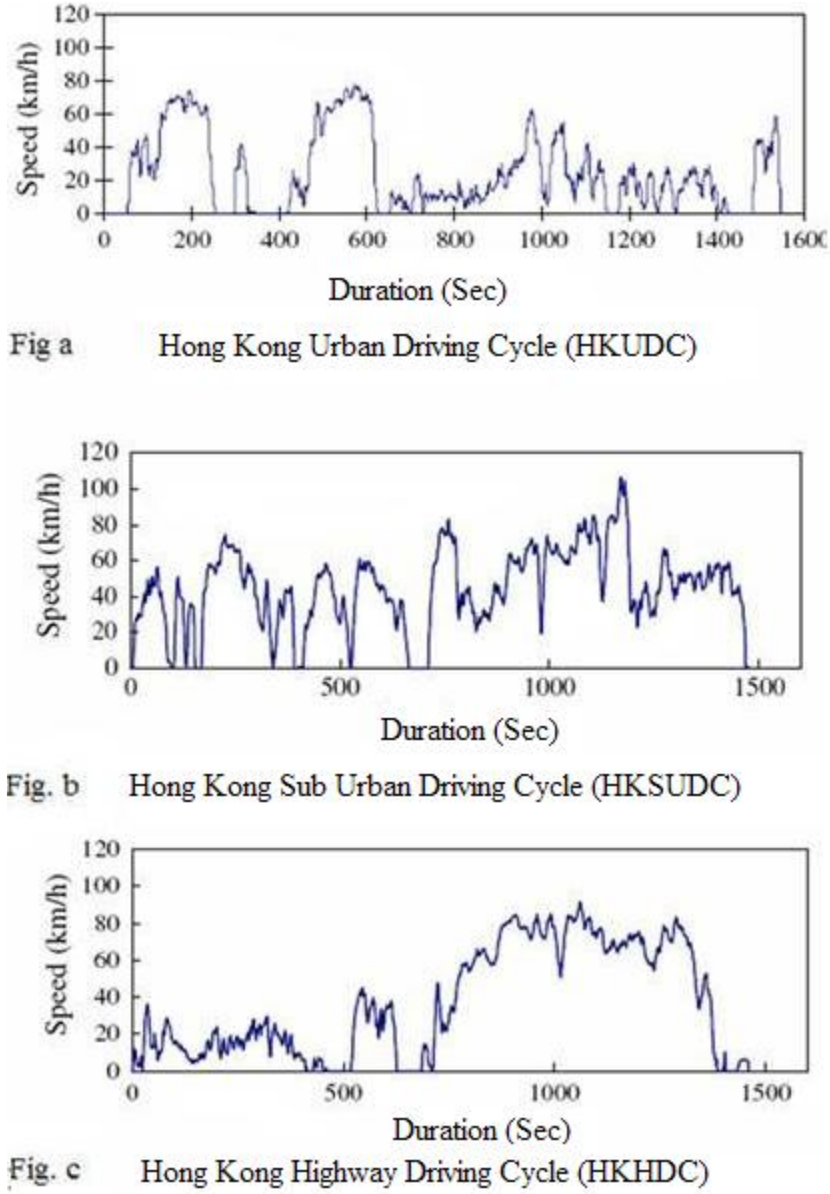


Figure 3.16 Hong Kong highway driving cycles (a) Urban (b) Suburban (c) Highway

(j) Fairbanks driving cycle

A winter driving cycle in the urban case was developed for emission measurement in low temperatures for the Fairbanks area of Alaska. It was found that speeds were lower in the winter season. Areas were selected, where CO exceeded the EPA standard and roads had an average daily traffic (ADT) greater than 5000; the chase car technique was used to record the speed-time sequence. Actual driving traces were used to calculate the average speed, average number of stops and average acceleration rates on each link. Best-fit data were selected after comparing the data with average values. Representative traces of each link were joined to form a complete Fairbanks driving cycle, using a weighted percentage (WP) length (Figure 3.17).

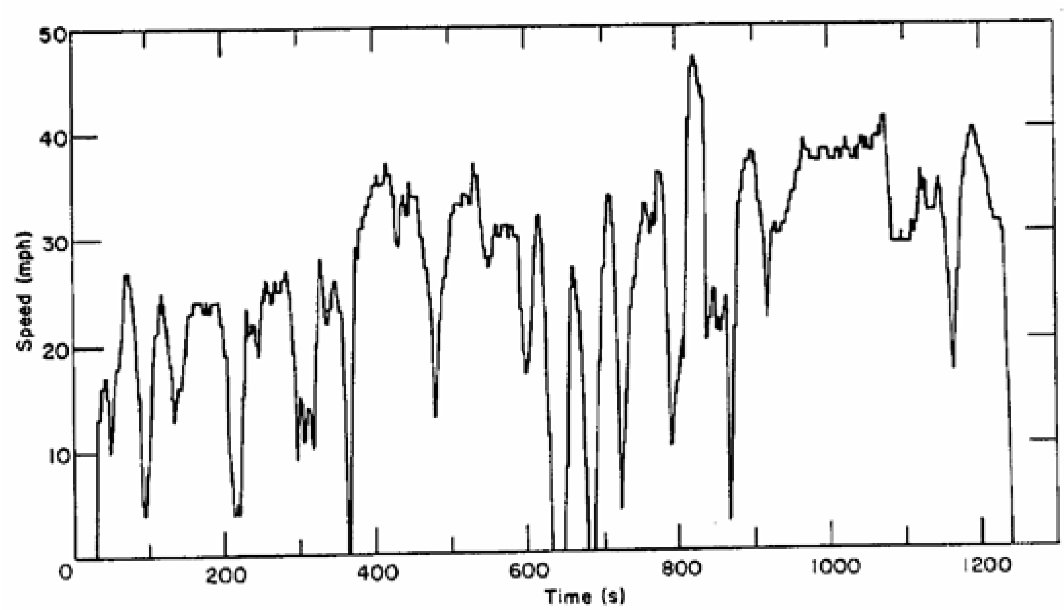


Figure 3.17 Fairbanks driving cycle

(k) Pearl River Delta (PRD) area driving cycle in China

Pearl River Delta (PRD) area in China comprises of three major cities in PRD, Hong Kong, Macao and Zhuhai. Hung et al., (2005) collected the real-time on-road driving data for the PRD using the car-chasing technique. Private instrumented car driven by an experienced driver was used to collect the second-by-second speed data in each city. Drivers were instructed to follow the target vehicles (i.e., the private cars) along selected route. In each test run, the chasing vehicle followed a randomly selected target vehicle on the selected route. If the target vehicle exited before the end of the route, another target vehicle was chosen until the end of the selected route.

A Global Positioning System (GPS) was installed in the same car to collect the speed data on the selected corridors on the period from November 2002, March 2003 and February 2004. The three PRD cities had a common feature of high proportions of acceleration and deceleration, in which Hong Kong has the highest average acceleration rate resulting in the highest positive kinetic energy (Figure 3.18). The results showed significant difference in driving characteristics.

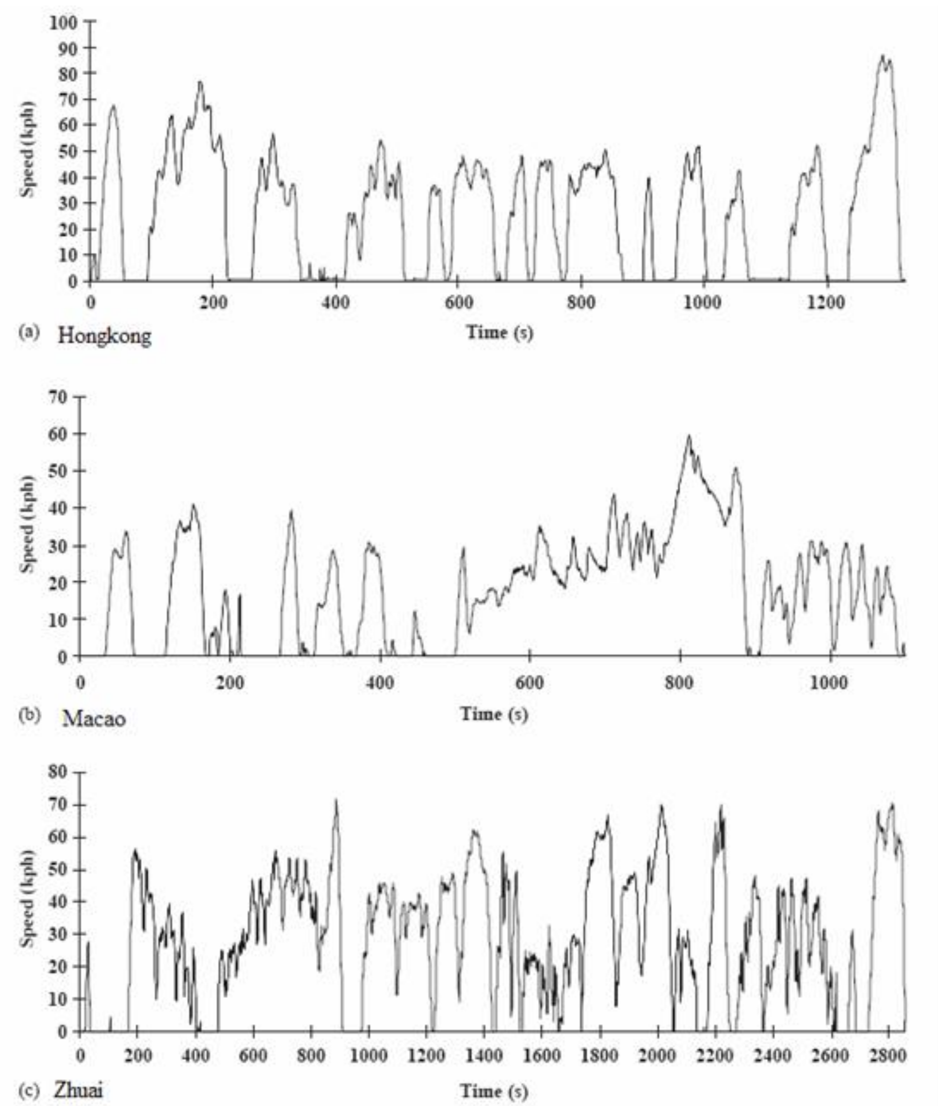


Figure 3.18 Weekday morning driving cycle in 3 cities: a) Hong Kong b) Macao c) Zhuhai

3.3.3 Review of other driving cycles

Light duty goods vehicles (LDGVs) are vehicles for professional usage whose laden weight does not exceed 3.5 tons. In, measurement of European emission factor for light vehicles, (Samaras and Ntziachristos, 1998) only 140 tests were recorded for LDGVs. In the early 1970s, Federal Test Procedure (FTP) was developed using a speed-time trace intended to represent vehicle operations in the Los Angeles urban area for measuring light-duty vehicle (LDV) exhaust emissions. Additionally, some other measurement campaigns were carried out in Europe (Rickeard et al., 1996; Montazeri and Naghizadeh, 2003).

Montazeri and Naghizadeh (2003) developed the driving cycle for simulation of vehicle exhaust gas emissions and fuel economy in the city of Tehran for light duty vehicles (Figure 3.19). The speed of vehicles was computed by measuring the frequency of the wheel rotation. The electronic part of the device was an electronic network that works together with a notebook computer as a data logger. The output of the network was connected to the notebook's parallel port, where the frequency of pulse signal was converted to vehicle speed. Two parameters were used for analyzing micro-trips for example, a) average speed (km h^{-1}) and b) idle time percentage (%). The proportions of time spent on four-road category in the whole set recorded data were used to find the duration of the cycle length (sec).

It was observed that as the average acceleration and deceleration of a cycle increase, the emissions and fuel consumption increases. The Tehran Car Driving Cycle has greater maximum acceleration and deceleration but smaller average acceleration and deceleration, than the FTP cycle, implying lower emissions and lower fuel consumptions.

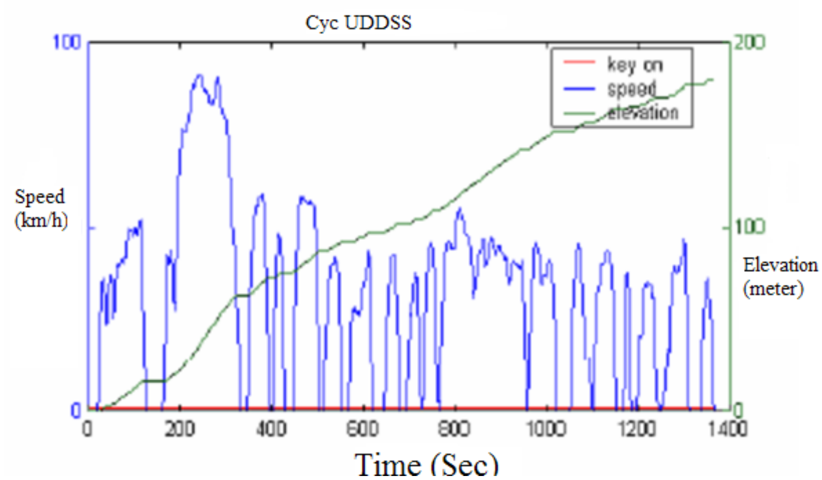


Figure 3.19 Tehran driving cycle

Joumard et al., (2003) characterized a real unit emission for light duty goods vehicles. Thirty-nine LDGVs owned by private companies and representative of the French vehicle fleet were selected randomly in the Rhône-Alpes and Paris areas (12 commercial cars, 12 light vans, 8 vans with laden weights of 2.5–3.1 tons (called 2.5 tons vans), and 8 vans with laden weights of 3.5 tons). These vehicles were equipped with sensors and used for their normal purposes by their owners during one month. Vehicle speed, engine speed and various temperatures were recorded at a 1 Hz frequency, and the load mass was evaluated through the measurement of the deformation of the vehicle suspension (shock absorber). Classification of trips according to the traffic conditions encountered allows the identification of trips with different dominant characteristics: motorway, rural, congested or fluid urban, or delivery trips. The trips that were the most representative of these classes were selected as driving cycles for LDV (Figure 3.20).

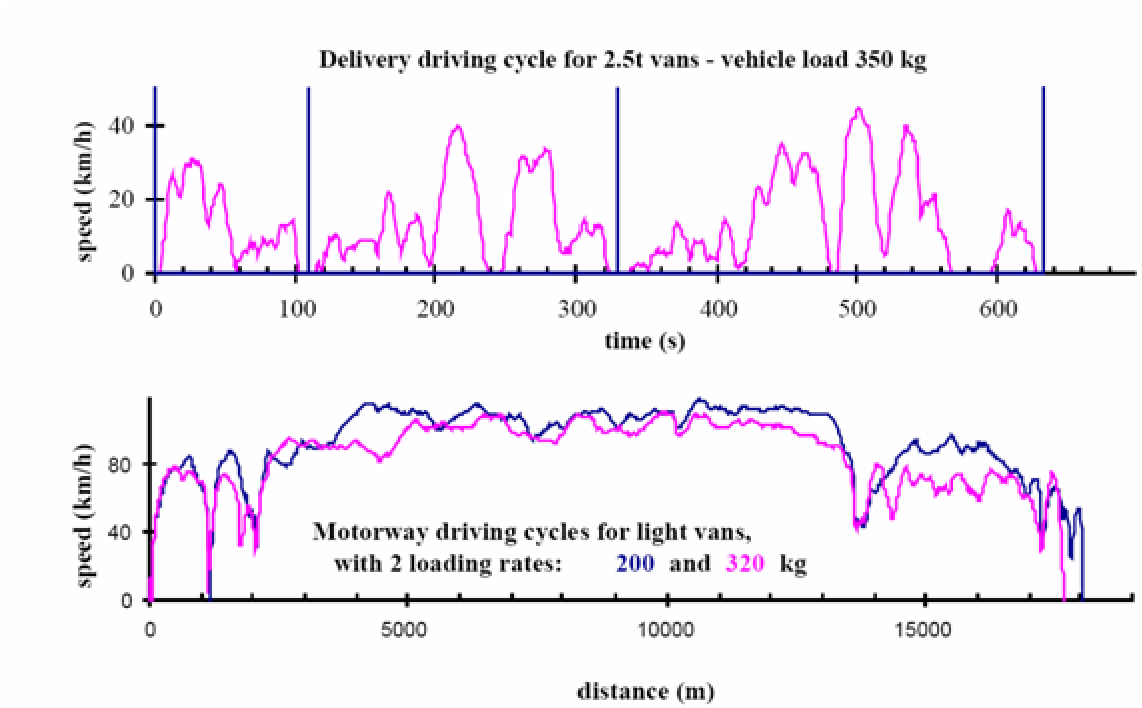


Figure 3.20 Examples of cycles developed: urban delivery cycle for 2.5 tons vans (in three very short trips), and motorway cycles with and without load for light vans (represented as a function of the distance).

Krishnamurthy (2005) developed a heavy-duty engine test cycle. This was representative of on-highway operation to provide an in-laboratory verification capability about engine in-use emissions standards. Engine activity data on heavy-duty vehicle use were collected and analysed under real-world conditions. A test vehicle was instrumented with the West Virginia University mobile emissions measurement system (MEMS). MEMS was a portable on-board tailpipe exhaust emissions measurement system, used to get engine operating conditions, vehicle speed, and in-use brake specific emissions of CO_2 and NO_X. The vehicle was tested on specific routes, which included a mix of highway and city driving patterns. The speed and torque points were normalized according to procedures described in the Code of Federal Regulations (CFR). Manuel et al., (2006) constructed a driving cycle for tricycles reflecting the actual driving conditions in Metro Manila (Figure 3.21). The instrumented vehicles were fitted with speedometer cables, speedometer with speed sensors to measure speed. Three distance sensors and

RPM (revolution per minute) sensors (primary and other) were employed to measure both speeds and acceleration.

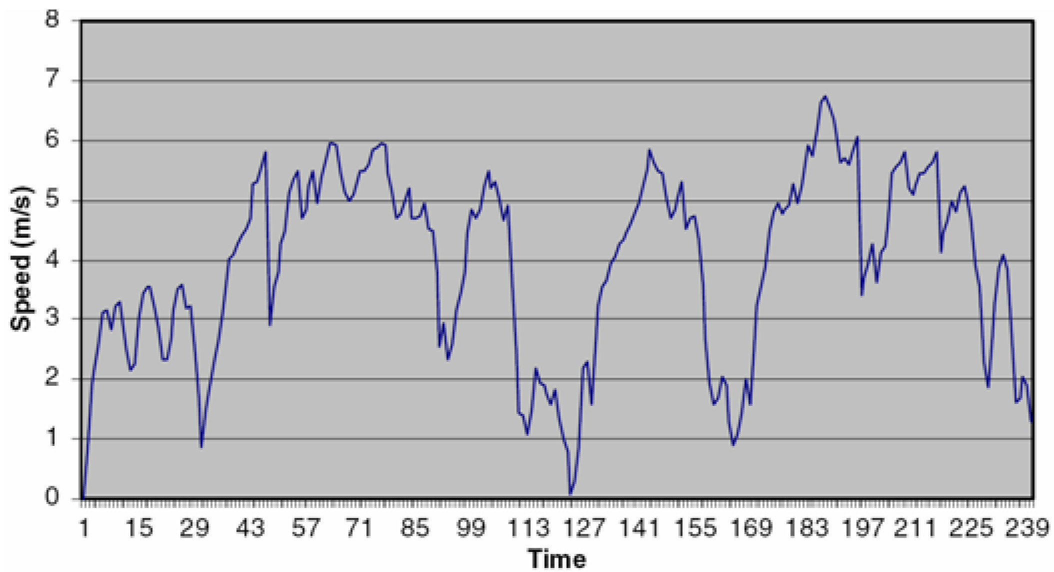


Figure 3.21 Metro Manila drive cycle

Alessandrini (2003) developed a cycle representing Italian driving style and traffic conditions, which adopted the methodology developed by Lyons et al., (1986). GPS was installed in an electric car to collect the geographical position of the vehicle. Four speed sensors, one per wheel, were installed to collect the vehicle speed, in addition to a triaxial accelerometer installed to collect slope and lateral accelerations. A total distance of 3136 km was covered in 120 h, 28 min and 37 s by six drivers on given routes in Rome. Over 75% of measurements were validated and used to synthesize the cycle.

3.4 Factors affecting driving cycle

From the above review, it is clear that driving cycles can be developed based on several factors. Table 3.2 shows examples of typical European driving cycles and their assessment parameters.

Table 3.2 Summary of European driving cycles and their assessment parameters

Driving cycle	Driving cycle condition	Assessment, Parameters	Vehicle Type	Authors (Year)
Common ARTEMIS Driving Cycle	69.7% of urban, 27.5% of rural and 2.8% of motorway	Average speeds, stop frequency and duration, gearbox usage (gear ratio changes)	77 number of cars	Andre (2004)
Driving cycle before and after installation of humps	Before and after the installation of 75mm high flat-top humps	Road speed and engine speed data from the three instrumented vehicles	500 number of passenger car	Boulter (1999)
Real-world European driving cycles,	High power car-35 number of run in motorway -42 number of run in urban-24 for urban, low powered car- 20, motorway-48, and number of rural 33 and urban,	Average speed, running speed, Average positive acceleration, number of accelerations, stop duration(%), number of stops per km	High- and low-powered cars	Andre et al., (2006)
Euro Driving Cycle	Urban, extra urban	Speed, acceleration	Motorcycle	Commission Directive 2002/51/EC
WMTC	Urban, rural, motorway of different part of world	Speed of vmax < 130 km h^{-1}, vmax ≥ 130 km h^{-1}	Motorcycle	UNECE, (GTR(2),2005)

3.5 Summary and discussions

Driving cycle is a representative speed-time profile of driving behaviour in a specific area/city. This section summarises the development of the driving cycle and the adopted methodology to derive this. The factors that affect driving cycles may include number of vehicles, flow of vehicle, traffic characteristics, age group of vehicle and driver, maintenance and inspection of the vehicles, characteristic of area, vehicle technology and type, road characteristics, driver behaviours, type of uses and climatic conditions. The details of each of these factors are presented in Table 3.2.

Driving cycle research has a number of applications, such as technological development of fuel and emission-efficient motorcycles.

There are different methods for data collection for driving cycle, which include chase car, chasing vehicle from origin to destination, and installing equipment like GPS in the motorcycle. Each method has relative advantages and disadvantages. Driving characteristics of each city are unique because of different vehicle fleet composition, driving behaviour and road network topography — the driving cycle for cars is not applicable for motorcycles. In addition, a driving cycle developed for one city is not applicable for other cities. Therefore, several projects on developing the driving cycle of motorcycle have been carried out to represent the real driving behaviour in different country. Chapter 4 reviews techniques for emission measurement and modelling.

CHAPTER 4 REVIEW OF EMISSION MEASUREMENT AND MODELLING TECHNIQUES

4.1 Introduction

An effective air-quality improvement program requires identification of emission inventory sources. An emission inventory is a listing and description of air pollutant emitting sources, including a quantitative estimate of pollutant emissions. In developing inventories, emission factors and emissions-producing activity data are used. An emission factor is the amount of pollutant produced per unit of activity. For highway vehicles, emission factors are typically expressed in grams of pollutant emitted per vehicle-mile of travel or grams of pollutant emitted per gram of fuel consumed or grams of pollutant emitted per unit of time (NRC, 2000). Thus, the activity data required for emission inventory development would typically be an estimate of total vehicle miles travelled, or total fuel consumed, or the time period of the emissions process.

Emission certification tests are also a means of comparing the emissions of vehicles and checking whether they stay within certain limits. The test cycles used depend on the type of vehicle. For heavy-duty vehicles, the engine is usually tested separately on an engine test bench. Light-duty vehicles, cars and motorcycles are mostly tested on a chassis dynamometer according to a predefined test cycle. This test cycle should generate repeatable emission measurement conditions and at the same time simulate real driving conditions. In Europe, the 'European Driving Cycle' (ECE) is used for the certification of light-duty vehicles, cars and motorcycles (see Chapter 3 for details). The related driving cycle has been discussed in Chapter 3. Prior to the certification test, the vehicle is allowed to soak for at least 6 hours at a test temperature of 20-30 ºC. Until recently, the engine was allowed to remain idle for 40 s before starting the measurement. From 2000 (Euro 3) onwards this idling period has been eliminated, meaning that emission sampling begins once the engine starts up. Emissions are usually sampled according to the

Constant Volume Sampling (CVS) technique, and the total emissions are expressed in g/km (gm km^{-1}) for each pollutant.

This chapter reviews the regulatory approach for emission measurement techniques in the UK and US for cars, motorcycles and other type of vehicles (including LDV and HGV). In addition, comparison of emission factors between passenger cars and motorcycles has been discussed. Finally, different aspects such as emission measurement process, equipment, and factors affecting emissions are discussed and summarised.

4.2 Regulatory methods for emission factor measurement

4.2.1 British Standards (BS) ISO 6460

ISO 6460 consists of the following parts, under the general title: Motorcycles measurement method for gaseous exhaust emissions and fuel consumption:

Part 1: General test requirements

Part 2: Test cycles and specific test conditions

Part 3: Fuel consumption measurement at a constant speed

ISO 6460 defines fundamental elements such as the measurement accuracy, test vehicle conditions and the details of the carbon balance method. Measurement of gaseous exhaust emissions and fuel consumption of test cycles can be conducted following of the ISO 6460 and ISO 6460-2:2007 (BS, 2007). Together with ISO 6460-3, they also give details of those measurements at a constant speed, which have been adopted in this research. The detail about regulatory emission standards has been discussed in Chapter 1.

4.2.2 Design manual for roads and bridges (DMRB)

Volume 11 of the Design Manual for Roads and Bridges reports on the procedures for environmental assessment Part 1, HA 207/07 on air quality guides and the assessment of the impact that road projects may have on local regional air quality (DMRB, 2008).

It includes a calculation method to estimate local pollutant concentrations and regional emissions for air, including those for carbon. In September 2001, a new database of emission functions was produced for ‘the Department of Transport ‘as a function of average vehicle speeds. The underlined functions are used in both the DMRB and the NAEI. These emission factors have been adopted in this research.

4.2.3 Computer programme to calculate emissions from road transport (COPERT III)

COPERT III was proposed for use in European Economic Area (EEA) member countries for compilation of the CORe INventory of AIR emissions (CORINAIR) project. In principle, COPERT III methodology can be applied for the calculation of traffic emission estimates at a relatively high aggregation level, both temporally and spatially, on a yearly basis. However, the methodology can also be used quite accurately, for the compilation of urban emission inventories with a spatial resolution of 1x1 km^2 and a temporal resolution of 1 hour.

COPERT III methodology covers exhaust emissions of CO, NO_X, VOCs, CH_4, CO_2, N_2O, NH_3, SO_X, and diesel exhaust particulates. Total emission estimates are calculated with a combination of firm technical data (e.g. emission factors) and activity data (e.g. total vehicle kilometres) provided by the user. All technical data depend on control variables, which may be modified by the user, to provide an accurate estimate depending on the type of application (Gkatzoflias et al., 2007).

4.2.4 COPERT IV

COPERT IV is an MS Windows software program aimed at the calculation of air pollutant emissions from road transport. In principle, COPERT IV has been developed for use by the National Experts to estimate emissions from road transport for inclusion in official annual national inventories. The COPERT IV methodology is also part of the (European Monitoring and Evaluation Programme) EMEP/CORINAIR Emission Inventory Guidebook under the UN-ECE Convention on Long-Range Trans-boundary Air Pollution and the EU directive on national emission ceilings. The use of a software tool to calculate road transport emissions allows for a transparent and standardised — hence consistent and comparable data collecting and emissions reporting procedure — in accordance with the requirements of international conventions and protocols and EU legislation (Gkatzoflias et al., 2007).

4.2.5 U.S. Environmental Protection Agency (U.S. EPA)

A number of models have been developed for emission factors. These include Mobile, EMFAC, MOVES and others. In principle, these models are computer programme, which link mobile source to predict emission in gm/distance. They are all having user-friendly interface that allows data input and scenario generation for emission. All these models are applicable for US[1].

4.3 Emission measurement techniques

4.3.1 Laboratory dynamometer-based measurements

(a) Constant Volume Sampling (CVS) Method

In laboratory testing, the test motorcycle is subjected to a reasonable simulation of real driving, in order to obtain realistic measurements of exhaust emissions. Since real driving involves constant transient change in speed, exhaust flow rates vary constantly as well. Thus, it is not enough to measure pollutant concentrations in the exhaust, it is important that the measurement technique must account for variations in exhaust flow rate as well. This is commonly accomplished by means of an ingeniously simple technique called Constant Volume Sampling (CVS). The key feature of the CVS system is that the pollutant concentration in the dilution tunnel is proportional to the pollutant mass flow rate in the exhaust. Thus, the integrated mass flow rate over a given driving cycle can be determined by integrating the concentration measurement alone. The details about maintaining the temperature and humidity are described in BS ISO 6460.

The constant volume sampler can collect exhaust samples when the motorcycle is driven on the chassis dynamometer. An infrared gas analyser is used for the automotive

1(Downloadable www.epa.gov. Accessed on 12 Jan 2008).

emission analyser. BS (British Standard) were followed. Before exhaust collection, each motorcycle must remain in the test room conditions for at least 8 hours for temperature stabilisation and before each measurement is conducted, the motorcycle must be warmed up for at least 5 minutes. A chassis dynamometer driving cycle is usually used to simulate the average driving pattern, based on the traffic jam conditions and street configuration of the city. For the current study EMDC, WMTC and ECE40 driving cycles were used for emission measurement (Chapter 8). These are normal emission measurement procedures.

4.3.2 On-road emission measurement using remote sensing

On-road emissions data can be obtained by using Remote Sensing Devices (RSD) alternatively, on-board instrumentation. Remote sensing devices use infrared (IR) and, in some cases, ultraviolet (UV) spectroscopy to measure the concentrations of pollutants in exhaust emissions as the vehicle passes a sensor on the roadway. Some applications of RSD include:

- Monitoring of emissions to evaluate the overall effectiveness of inspection and maintenance (IM) programs.
- Identification of high-emittance vehicles for inspection or enforcement purposes moreover, development of emission factors.

The major advantage of remote sensing is that it is possible to measure a large number of on-road vehicles (e.g. thousands per day). The major disadvantages of remote sensing are that it only gives an instantaneous estimate of emissions at a specific location for specific vehicle, and cannot be used across multiple lanes of heavy traffic. Furthermore, remote sensing is more suitable for fair-weather technology (Rouphail et al., 2000).

4.3.3 On-board real world emission measurement

On-board emission measurement is widely recognized as a desirable approach for quantifying emissions from vehicles since data are collected under real-world conditions at any location travelled by the vehicle. On-board emissions measurement has not been widely used because it has been prohibitively expensive. Therefore, instrumented vehicle emissions studies have typically focused on a very small number of vehicles (e.g. Kelly and Groblicki, 1993; Cicero-Fernandez and Long, 1997; Gierczak et al., 1994; Tong et al., 2000). In other studies, researchers have measured engine parameters only (Denis et al., 1994; LeBlanc et al., 1994; Guensler et al., 1998; West et al., 1997).

Portable emissions measurement systems (PEMS) are very beneficial in obtaining data that are truly representative of real-world emissions. Laboratory dynamometer-based testing has been carried out for years and there have always been questions on how well the driving cycles represent real-world conditions.

However, in the last few years, efforts have been underway to develop low-cost instruments capable of measuring both vehicle activity and emissions. For example, the U.S. Environmental Protection Agency (EPA) developed an on-board measurement system for both light and heavy-duty vehicles (Scarbro, 2000). Private companies such as Clean Air Technologies International Inc., Sensors Inc., Ford Motor Company, and Horiba, Probike Co. have developed commercial versions of on-board instruments (Vojtisek-Lom and Cobb, 1997; Butler, 2001; Wilson, 2002, Probike, 2008).

Vehicle emissions vary because of variation in facility (roadway) characteristics, vehicle location, vehicle operation, driver, or other factors. This can be represented and analyzed more reliably with on-board emissions measurement than with the other methods. This is because measurements are obtained during real world driving, eliminating the concern about non-representativeness that is often an issue with dynamometer testing, and at location based on road emission measurement, eliminating the sitting restrictions inherent in remote sensing.

However, statistical concerns complicate the development of real-world vehicle emissions inventories. The evaluation of emissions control program effectiveness and the process by which manufacturers certify that their vehicles are in compliance with emissions standards. Wenzel et al., (2000) described five major statistical issues that can complicate the analysis of emissions data as follows:

i. inter- and intra-vehicle emissions variability,
ii. skewness of the distribution of emissions from in-use vehicles,
iii. the difficulty of obtaining statistically representative vehicle samples,
iv. the influence of repeat testing on only a subset of the vehicle fleet,
v. Differences among common test methods and pollutant measurement devices.

The issue was reported in light of three relevant regulatory purposes: (a) testing the compliance of in-use vehicles with certification standards (b) evaluating the effectiveness of vehicle inspection and maintenance programs and (c) estimating emissions inventories for air quality modelling and compliance planning.

However, it is important to understand that on-road emissions data collection cannot completely replace laboratory-based programs. On-road data collection results in real-world emissions data that are influenced by numerous factors including varied vehicle characteristics, traffic, driving behaviour, road grade, and even meteorological conditions. All of these factors (and several more) affect tailpipe emissions and it is very difficult to control these factors individually. For example, if it is desired to carry out testing under specific temperatures, it will be difficult to design in the real world. In the laboratory, it is somewhat easier to control specific factors individually so that the 'confounding factors' issue is minimized (Younglove et al., 2005). In our study on-board measurement on two different motorcycles has been made to understand the real world, emissions for Edinburgh (refer to Chapter 8 and 9 for details).

4.3.4 Emission measurement data from inspection and maintenance (I/M) testing

Inspection and maintenance (I/M) programs identify high-emission motorcycles and help to reduce air pollution, but they have been criticized for being cost-ineffective. I/M programs were first introduced in California in the 1960s to assure maintenance of emission-control systems and regulate the release of CO, HC and NOx (Samaras and Kitsopanidis, 2001). These programs usually consist of a periodic measurement of the exhaust emissions together with visual and functional inspection of the emission-control hardware. I/M programs for 'in-use' motorcycles in urban areas of Taiwan were introduced in 1996 and expanded to the entire region in 1998. It was also used in Portland, Oregon to identify the characteristics of vehicles that are significantly associated with carbon monoxide and hydrocarbon emission test failures (Bin Okmyung, 2003).

Vehicle age, engine size and odometer reading all played a significant role in determining I/M test results, as do vehicle make and class. Beydoun and Guldmann (2006) used the emission model using I/M data sets from Massachusetts, Maryland, and Illinois for 2001. They developed the relationships between vehicular emissions and characteristics, with a particular focus on which vehicle-specific variables such as age, mileage, weight, engine characteristics, fuel economy and general maintenance, which are predictors of exhaust emissions and test failure. They also tried to find out how these relationships varied across vehicle make and type (car versus truck), and time of year. Finally, they measured the relationships between vehicle emissions and test failures, and a large number of explanatory variables. However, in Edinburgh or the UK there is no I/M testing programme for motorcycles, therefore data about history of emission patterns and detailed specific vehicle specification are not available for analysis.

4.4 Review of previous studies on emission measurement

4.4.1 Emission measurements of motorcycles

Most of the literature on emission measurement of motorcycles was carried out in the far East countries (e.g. Taiwan, Bangkok). However, a few studies reported some studies in Europe.

(a) Previous studies in Taiwan

Tsai, et al., (2000) measured emission factors of carbon monoxide (CO), nitrogen oxides (NO_X) and total hydrocarbon (THC) concentrations of volatile organic compounds (VOCs) from new and in-use motorcycles. CO, NO_X, THC measurements and the others were for stage emissions under different driving patterns for hydrocarbon specification. The tailpipe of motorcycles was directly connected to a sampling system under testing conditions for the entire cycle. Exhaust gases were emitted to a constant volume system (chamber) and diluted using indoor air, then loaded into sampling bags. For different driving pattern samplings, five vacuum boxes were applied to contain various gas samples, and each vacuum box contained a 3-litre Tedlar bag. Exhaust gas was diluted using room ambient air pumped with a controlled flow-rate. Several control valves were used to guide samples of different driving patterns into various designated Tedlar bags.

Analysis for CO, THC, and NO_X was done by a HORIBA MEXA-8320 Analyser. The background concentrations of indoor air were also analysed routinely and deducted from the test results. In the analysis laboratory, hydrocarbon species in the sample bags were pre-concentrated by a purge and trap system (AERO Trap Desorber, Tekmar, 6000) and then analysed by a GC/MS analyser (Hewlett Packard 5890 II & Hewlett Packard 5972). The performance of GC/MS was evaluated with perfluorotributylamine for quality control. Except for NO_X, the emission factors of CO, THC and VOCs from in-use motorcycles were all higher than those from new ones. The most substantial differences were in CO. The CO emission factor of in-use motorcycles was approximately 8-15 times higher than the new ones in 2-stroke engines and 6 times higher in 4-stroke engines. In-use motorcycles also contributed more THC per kilometre than the new ones, especially for 2-stroke ones (4-6 times more). In addition, used 2-stroke engines emitted more THC per kilometre travelled than used 4-stroke ones.

Yang et al., (2003) investigated volatile organic compound emission during cold starts. They collected samples through a heated line through a dilution tube and put them into Tedlar bags to be analysed within two hours of collection. HP-624 column (30 m x 0.53 mm internal dia.) was used for separation of light aromatics compound; the collected sample was analysed by capillary gas chromatography (Hewlett Packard HP 5890 Series equipped with flame ionization and electron capture detectors). VOC compounds identified in the motorcycle exhaust (ME) were benzene, toluene, Ethyl benzene and xylenes. These were separated and quantified. Toluene and xylenes were observed as the most abundant aromatic VOC in the motorcycle exhaust emission. If compared with 4-stroke gasoline, the VOC emission from 2-stroke motorcycles is relatively higher (by at least 12 times). The similar studies were carried out by Tsai et al., (2003, 2005) developed speciation of volatile organic compounds (VOCs) from motorcycle engine exhaust for different driving modes. In another study, Yang (2005) investigated size distribution of particulate polycyclic Aromatic Hydrocarbons in the diluted 4-stroke motorcycle exhaust.

Tsai et al., (2005) developed a local real-world driving cycle for motorcycles for emission factor measurements for Kaohsiung metropolitan area (KHM) of Taiwan. Nineteen motorcycles (including ten 2-stroke of 50 cm^3 [3 new and 7 in-use] and nine 4-stroke [3 new and 6 in-use] of 125 cm^3 engines were tested once for ECE and KHM. Gas samples were collected for the entire cycle (both ECE and the selected KHM cycle) with an automated instrument, a constant sample volume (HORIBA, CVS- 51S). The tailpipe of each motorcycle was connected directly to a sampling bag for the entire test cycle. The gas was analysed for CO, THC, NO_X and CO_2 using gas analyser.

Results indicated the background concentrations were approximately 2 ppm for CO, 6 ppm for Total Hydrocarbon (THC), 0.1 ppm for NO_X and 0.01% for CO_2, which were much lower than those of the sampling. The fuel consumption of new and in-use 2- and 4-stroke motorcycles is presented in Table 4.1. The emission factors and fuel consumption of 2-stroke motorcycles was 10% higher than that of 4-stroke motorcycles. The fuel consumption in the KHM motorcycle driving cycle was also about 10% higher than that of the ECE cycle, which indicated that the ECE cycle was unsuitable to measure the fuel consumption in the Kaohsiung metropolitan area. The in-use motorcycles also showed a 10% fuel increase over the new ones. Consequently, a localised driving cycle accurately described the traffic conditions and represents drivers' habits.

Table 4.1 Emission factors for 2- and 4-stroke motorcycles with ECE and KHM

Engine Type	Type no.	Driving Cycle	CO (gm km^{-1})	HC (gm km^{-1})	NO_X (gm km^{-1})	CO_2 (gm km^{-1})	Fuel consumption (lit. km^{-1})
2-stroke	New N=3	ECE	1.880±0.008[a]	1.250±0.170	0.001±0.001	60.800±1.400	0.028±.001
		KHM	4.710±0.250	1.880±0.1700	0.002±0.001	60.100±1.800	0.031±.001
		KHM/ECE	2.500	1.500	2.000	0.990	1.110
	In use N=7	ECE	7.020±2.000	2.800±1.790	0.018±0.010	52.400±6.800	0.030±.0030
		KHM	10.690±5.390	3.630±2.280	0.025±0.016	53.000±6.700	0.034±.0050
		KHM/ECE	1.510	1.300	1.390	1.010	1.130
4- stroke	New N=3	ECE	1.170±0.690	0.290±0.130	0.150±0.060	59.500±4.700	0.026±.0026
		KHM	2.280±0.980	0.480±0.250	0.170±0.040	61.300±3.600	0.028±.0026
		KHM/ECE	1.950	1.660	1.130	1.030	1.080
	In use N=7	ECE	5.610±4.290	0.580±0.200	0.180±0.07	54.700±4.300	0.028±.0028
		KHM	7.410±4.900	0.790±0.210	0.260±0.06	55.900±5.920	0.030±.0030
		KHM/ECE	1.320	1.360	1.440	1.020	1.070
2-4 stroke	New	ECE	1.610	4.310	0.007	1.020	1.080
		KHM	2.070	3.920	0.012	0.980	1.110
	In use	ECE	1.250	4.830	0.100	0.960	1.070
		KHM	1.430	4.590	0.100	0.950	1.130

a: Standard deviation

(b) Previous studies in Europe

Czerwinski et al., (2003) reported on emission factors and influences on particle emissions of modern 2-stroke scooters in Europe. A chassis dynamometer was used to measure regulated exhaust gas emissions. The initial 4 minutes were used for the preparation of the measuring apparatus for the subsequent stationary measurement. The 2-stroke engine has generally higher nano-particulate (NP) emission. Anderson et al., (2003) investigated the unregulated emissions from a range of twelve 2- and 4-stroke motorcycles with respect to various drive cycles, engines, and after-treatment technologies. Data were generated using specialised Fourier Transform Infrared Spectroscopy (FTIR), On-line Mass Spectrometry (OLMS) and Condensation Particle Counter (CPC) instrumentation for the real-time determination of individual inorganic, hydrocarbon and particle number concentration. Analyses of particulate mass, mass weighted particle size distribution, and further chemical composition analyses including particle and vapour phase polycyclic aromatic hydrocarbons (PAHs) were conducted. Testing was conducted over three drive cycles described by the following directives using a constant volume sampler (CVS):

- 97/24/EC (Chapter 5, Annex 2)
- 98/69/EC (Motorcar cycle)
- WMTC version 7 (developmental cycle)

Conventional measurements and comparison of NO results for motorcycles are presented in Figure 4.1.

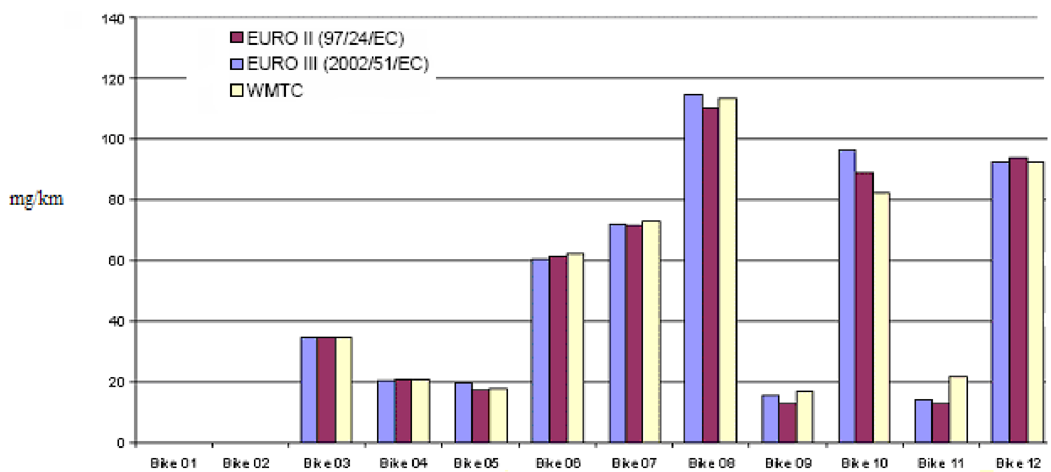


Figure 4.1 NO emissions for ECE (97/24/EC) cycle of motorcycle

NO emissions from all bikes were clearly dominated by NO (>85%) (Figure 4.1) ranging from 18 mg/km to 118 mg/km while most motorcycles showed little NO_2 ranging from 2 to 12 mg/km (Figure 4.2). The major exception was Bike 08, the 2-stroke DI equipped with an oxidation catalyst, which showed NO_2 emissions as presented in Figure 4.2. Formation of NO_2 across an oxidation catalyst is not unexpected. Similarly, N_2O production is known to be one of the products of NO reduction over catalysts. The other exceptions were air-cooled; Bike 10 and Bike 12, which produced 1 mg km^{-1} and 11 mg km^{-1} of nitrogen dioxide respectively (presented in Figure 4.2).

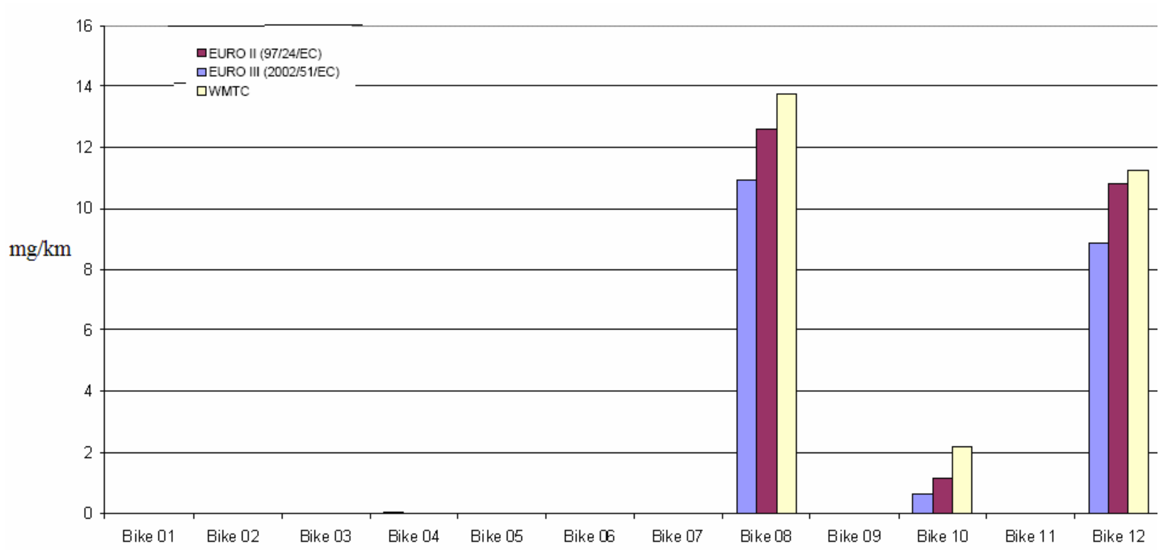


Figure 4.2 NO_2 emissions for ECE (97/24/EC) cycles

(c) Previous studies in the UK

Bosteels et al., (2005) reported emission measurement on a representative selection of five larger capacity (>600 cc) Euro 2 motorcycles, Euro 3 and World Motorcycle Test Cycles in the UK. They found that NO_X control was critical for future motorcycle technologies; the WMTC especially produces high NO_X in relation to the higher rates of acceleration, higher maximum speed and more transient nature of the cycle than current Euro 2 and 3 cycles as shown in Figure 4.3.

Also HC and CO emissions were significantly influenced by the ambient start of cycles. They did an investigation into varying air-fuel ratios (AFR) to see the effect on NO_X conversion. Even small changes in AFR had an effect on NO_X.

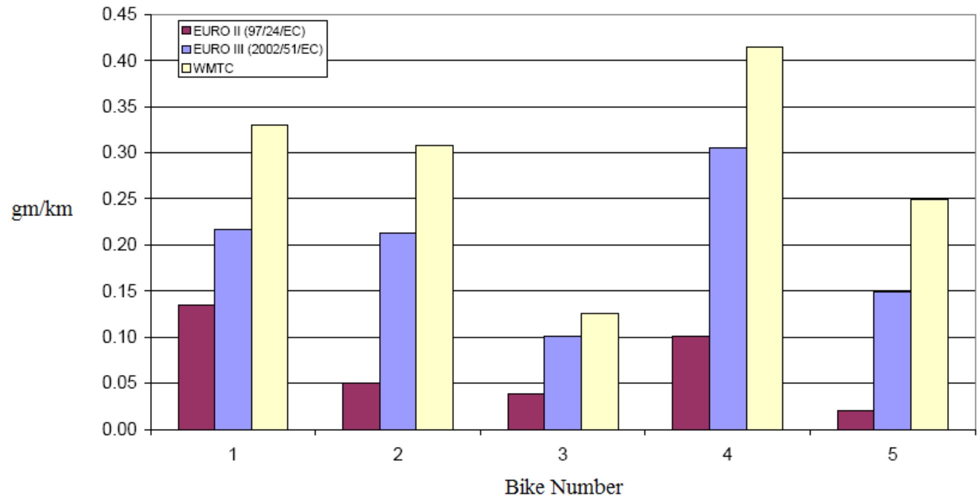


Figure 4.3 Average NO_X emission

A catalyst build was defined after final optimised AFR, which allowed Euro 3 emissions levels to be achieved. Catalyst formulations showed good potential for improved control of NO_X, CO and HC over future cycles.

Saxer et al., (2006) measured benzene, toluene, and C2-benzene emissions of 4-stroke motorcycles using chemical ionization mass spectrometry (CIMS). Durations of the cold start were introduced in the legislative urban driving cycle to cover extra emissions and investigate the emission characteristics at transient driving from 0 to 135 km h^{-1} on the Common ARTEMIS Driving Cycle. In addition, the benefits and risks of the currently available 3-way catalyst technology (TWC) were explored. Benzene, toluene, and C_2-benzene cold start emissions were in the range of 230-290, 920-980, and 950-1270 mg km^{-1} respectively for the TWC motorcycles, exceeding those without catalyst by more than a factor of three. Benzene, toluene and C_2-benzene emission factors in the range of 10–140, 10–160 and 10–170 mg km^{-1} were found for hot engine/catalyst in TWC motorcycles, while without a catalyst the corresponding emission factors were higher, varying from 40-260, 100-500 and 110-480 mg km^{-1} respectively. Table 4.2 displays benzene, toluene and C_2-benzene emission factors (mg km^{-1}) of 4-stroke motorcycles in CADC. It was observed that CADC urban driving phase I (Urban) has higher emission factors for benzene, toluene, and C_2 benzene emission.

Table 4.2 Benzene, toluene & C_2-benzene emission factors of 4-stroke motorcycles in CADC

Emission factors ($mg\ km^{-1}$)	Honda Shadow without Cat	Suzuki VS 800 GLP without Cat	Honda VFR 800 F1 with TWC	BMW R1150 with TWC
Benzene				
CADC I[a]	77	255	36	141
CADC II[b]	39	88	14	44
CADC III[c]	56	75	67	6.8
Toluene				
CADC I[a]	235	498	92	131
CADC II[b]	98	192	37	28
CADC III[c]	109	150	157	14
C_2-Benzene				
CADC I[a]	268	477	98	85
CADC II[b]	108	189	41	20
CADC III[c]	114	140	171	13

a. Phase I represents urban driving with mean velocity of 17.5 $km\ h^{-1}$
b. Phase II represents extra-urban driving with mean velocity of 69.3 $km\ h^{-1}$
c. Phase III represents highway driving with mean velocity of 116.4 $km\ h^{-1}$

Both studies (Bosteel, 2005 and Saxer, 2006) showed the impact of catalyst on emission reduction.

4.4.2 Emission measurements in passenger cars

In contrast to motorcycles, most of the studies on emission measurement were undertaken for cars in Europe. The following paragraphs summarise the some of the main studies in Europe.

Fontaras et al., (2008) employed a Euro 2 equipped with a turbocharged direct injection diesel engine with an oxidation catalyst for sampling and analysis of gaseous regulated pollutants in accordance with the European regulation (Directive 70/220/EEC and amendments). A proportional sample of diluted exhaust gas was collected using the CVS technique in a different Tedlar bag per driving cycle. Pollutant analysis was performed at the end of the testing, using laboratory analyser (NDIR sensor for CO and CO_2, CLD sensor for NO_X and FID sensor for HC). Particulate matter (PM) mass was collected on 47 mm PTFE-coated fibre filters (Pallflex TX40HI20-WW), which were conditioned for 24 hours at a constant room temperature (22 ºC) and humidity (40%) before and after the measurement and prior to weighing. Filter weighing was performed on a Mettler Toledo microbalance. They reported emission factors of CO, HC, and NO_X using bio-diesel as fuel. The estimated emission factor on different driving cycle is presented in Figure 4.4. Urban driving cycle (UDC) cold driving cycle shows higher emission factors for CO, HC, and PM (except NO_X).

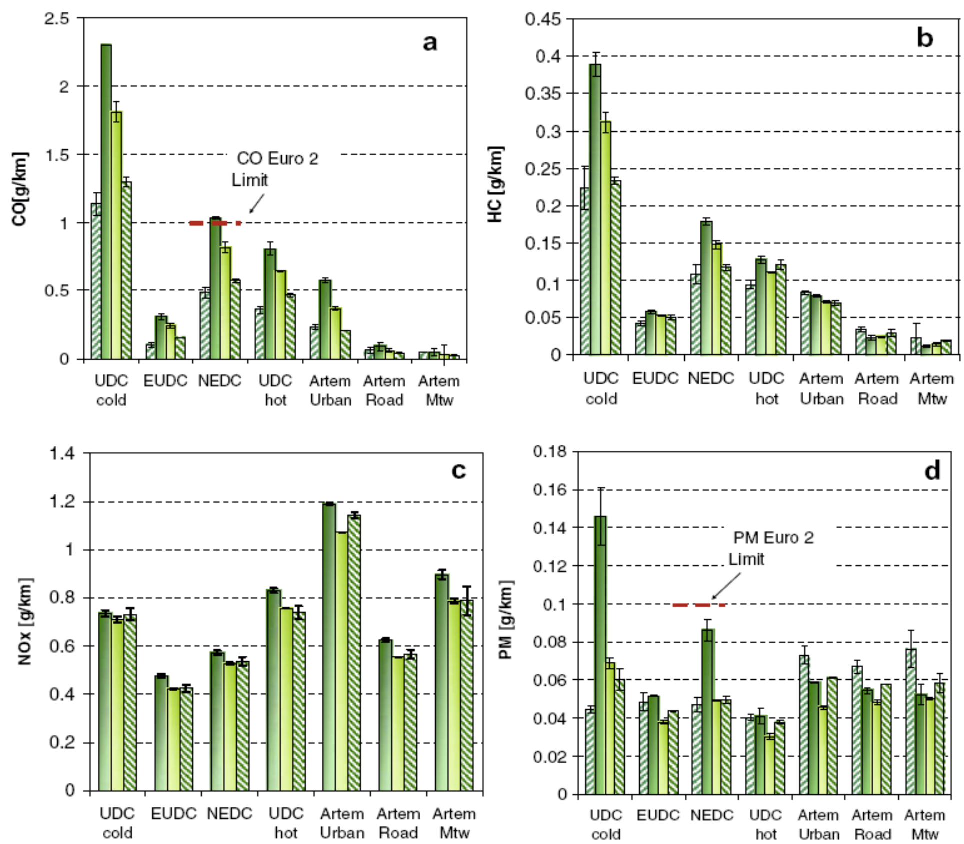


Figure 4.4 Emission measurement results from bio diesel fuel a) CO b) HC c) NO_X and d) PM

Andre and Rapone (2008) analysed and modelled the pollutant emissions from European cars concerning the driving characteristics and test cycles. They first constructed a set of contrasted cycles specifically designed for characterizing the influence of the driving conditions. Thirty vehicles were tested on those cycles considering their influence on the hot emission rates of the regulated pollutants (CO, HC, NO_X, CO_2, and PM). Slight high-emission of the NO_X between Euro 3 and Euro 2 diesel cars was noted with the overall difference was less than 9%. Indeed, there was no significant change regarding Diesel NOx limit between these two regulations (in Euro 2, the only HC + NO_X limit was 0.7 gm km^{-1}; it decreased to 0.56 gm km^{-1} in Euro 3, with the possibility of NOx reaching 0.5 gm km^{-1}, while the main NO_X reduction was expected in Euro 4 at 0.25 gm km^{-1}). A more significant reduction was set up for petrol cars. NO_X emissions exceeded the standard limit in real-world test conditions.

The prevalence of the driving type (urban, rural, motorway), the vehicle category (fuel, emission standards) and emitting status (high/normal) were demonstrated through ANOVA test to analyse emissions in different categories. Urban driving led to high CO_2, HC, and NO_X emissions from diesel and petrol cars. Congested driving results high CO_2 (diesel and petrol) and high diesel NO_X emissions. On motorways, the very high speeds generated high CO_2 while unsteady speeds induced higher NO_X from diesel and CO from petrol over-emissions. Urban diesel emissions were mostly due to stops and speed parameters, while petrol emissions were rather sensitive to acceleration parameters. On motorways, diesel NO_X and CO_2 emissions rates increased with the speed variability and occurrence of high speeds, while CO_2 and CO over-emission from petrol cars were linked to the occurrence of strong acceleration at high speeds.

A modelling approach based on partial least square regression was tested which explained its ability to distinguish satisfactorily the emissions according to the dynamic related parameters in particular when considering the two-dimensional distribution of instantaneous speed and acceleration. The results of this model coefficient of correlation (R^2) are presented in three different categories (Table 4.3).

Table 4.3 Model R^2 for the Euro 3 Petrol 1.4–2.0l for normal to high emitters cars

Emission (gm km^{-1})	Model MG	Model MVA	High-level Model
Normal and High Emitters			
CO	0.46	0.46	0.48
HC	0.27	0.29	0.30
NO_X	0.23	0.28	0.28
CO_2	0.80	0.85	0.85
Normal emitters			
CO	0.39	0.41	0.42
HC	0.30	0.32	0.33
NO_X	0.23	0.26	0.27
CO_2	0.83	0.86	0.86
High Emitter			
CO	0.79	0.75	0.79
HC	0.41	0.43	0.42
NO_X	0.36	0.52	0.50
CO_2	0.88	0.93	0.92

Pelksman and Debal (2006) compared on-road emissions with emissions measured on chassis dynamometer test cycles under the DECADE project. This was carried out under the EU 5th Framework Programme to develop software package to predict vehicle fuel consumption and emissions for a given distance–speed profile. In order to give input to the model, specific light duty vehicles (diesel and petrol car) were subjected to intensive measurements on engine dynamometers, chassis dynamometers, and proving ground and in real traffic. The data recorded in Belgium resulted in a cycle, commonly referred to as the ‘MOL’ cycle (Pelkmans et. al., 2002). The MOL cycle consists of three phases: urban, rural and motorway. Diesel passenger cars (Euro 3) and small petrol passenger cars (Euro 4) were subjected to chassis dynamometer tests on ECE and MOL driving cycles for emission measurement of CO, NO_X, CO, and CO_2.

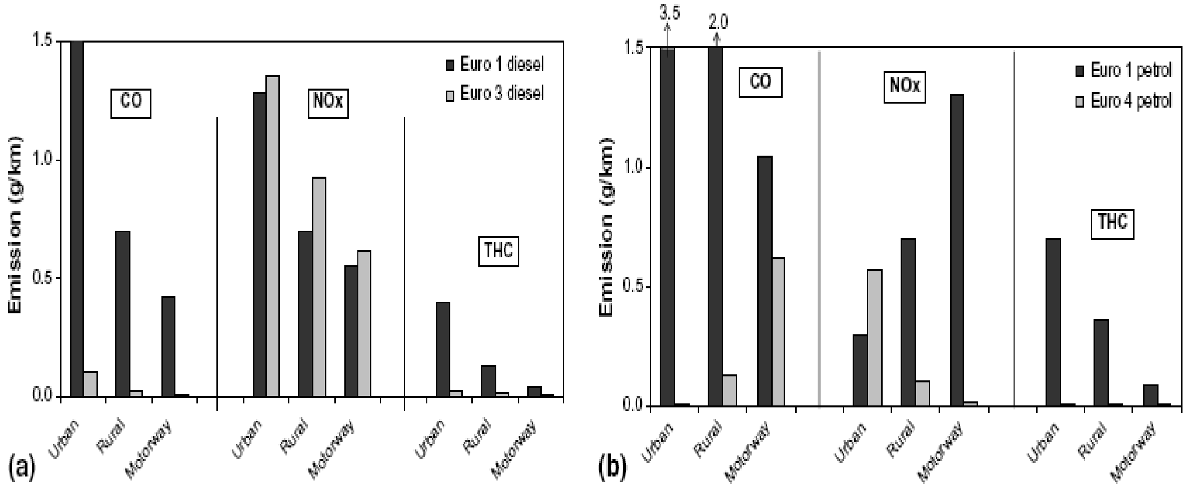


Figure 4.5 Real traffic measurements around Mol (Belgium): Comparison (a) Euro 1 diesel and Euro 3 diesel and (b) Euro 1 petrol vs Euro 4 petrol

Figure 4.5 shows that there was a spectacular decrease in CO and THC emissions, both for diesel and petrol vehicles. In the case of diesel vehicles, this was related to the introduction of the oxidation catalyst; whereas, in petrol vehicles, this is related to improved lambda control. NO_X emissions have remained at approximately the same levels for the diesel car. The NO_X reducing measures, which were introduced to achieve recent Euro limits, seem to be compensated by the higher power of the newer diesel cars. In the case of petrol cars there used to be a clear correlation between average speed and NO_X emissions (highest in motorway traffic). The more sophisticated lambda control in recent petrol car models has however changed this relation (higher NO_X in urban traffic, very low NO_X in motorway traffic). Differences in weight and engine power may have an important impact on the comparison between older and newer vehicle models to illustrate a trend.

4.4.3 Emission measurements in other types of vehicle

Joumard et al., (2003) characterized a real unit emission for CO, HC, NO_X, CO_2 and particulate emissions together with fuel consumption for light duty goods vehicles (LDGVs). The vehicles were tested on a chassis dynamometer equipped with a roller of

1219 mm in diameter. Each sample vehicle was tested according to its specific set of cycles. CO, CO_2, HC, NO_X emissions, and particulate mass were analyzed and fuel consumption were calculated using the carbon balance method. The increase in on-board load generally leads to a decrease in CO, HC, and particle emissions, and an increase in the NO_X and CO_2 emissions. The evolution of the vehicle models appears to have had a positive impact on the CO, HC and particle emissions, but little impact on the NO_X emissions, and a negative impact on the CO_2 emissions.

In another study by Joumard (2004) 27 diesel LDGVs were tested on a chassis dynamometer using driving cycles. Each vehicle category was tested according to 6-9 hot cycles, differing by their kinematics and their loading rates. Emission of CO, HC, NO_X, $CO_{2,}$ and particulate emissions together with fuel consumption were evaluated. Results demonstrated the average cycle speed, the load, and the vehicle category influence on emissions. These measured emissions were quite different from passenger car emissions, and from emissions calculated using the European Meet/COPERT III model.

Shah et al., (2004) measured emission rates of particulate matters and elemental and organic carbon from in-use diesel engine. The heavy-duty diesel trucks (CARB HHDDT cycle) was selected for estimating the emission rate for different vehicle operating conditions. The driving cycle simulated four basic HHDDT operational modes: cold start/idle, creep, transient, and cruise (the cold start mode was followed by a 10 minute idle). The weight of the mobile emission laboratory (MEL) provided engine load during on-road testing for a number of creep phase, which simulates slow driving such as stop and go in heavily congested traffic. PM was collected using the secondary dilution system (SDS) installed in the MEL. The SDS includes an impactor of heavy heavy-duty diesel trucks (HHDDTs) and back-up transient phase that simulates light to medium traffic arterial road driving; installed at the inlet of the SDS for removal of particles with an aerodynamic diameter greater than 2.5 nm. There were a number of parallel sample channels for simultaneous collection of multiple filter media and a temperature control to maintain filter face temperatures at 41F (5°C). Diluted exhaust was iso-kinetically withdrawn from the primary dilution tunnel and further diluted with clean, dry dilution air. This diluted sample is then split into several channels for the collection of various filter media and gas-phase samples generators (BUGs) operating under real-world conditions.

Cocker et al., (2004) developed a mobile emission laboratory (MEL) to measure regulated gaseous emissions from diesel engines. This unique mobile laboratory provides information on integrated and modal regulated gaseous emission rates and integrated emission rates for volatile and semi-volatile organic compounds and particulate matter during real-world operation. Total emissions are captured and collected from heated probes, “heated filters.” Sample conditioning is used to prevent condensation and remove moisture in the system. Table 4.4 shows NO_X, CO, CO_2, and THC during each mode of this California Air Resources Board (ARB) cycle for several repeat tests performed on several non-consecutive days. The NO_X emission factors were 76.76, 33.63, and 34.11 gm km^{-1} for the creep, transient, and cruise modes respectively. The largest difference was seen in the creep mode. NO_X emission rates were compared with the transient and cruise mode that indicated impact of congested conditions on inventory estimates of NO_X emissions. The lack of a significant drop in NO_X emission rates between the transient and the cruise mode were resulted from the relatively high off-cycle engine operation encountered during portions of the cruise mode.

Table 4.4 Emissions measured during the 4 –mode ARB cycle for CAT-C15 engine

	N[a]	Distance (m)	Time (s)	NO_X	CO_2	CO	THC
Cold Start/idle (g min^{-1})	5	NA[b]	600	2.730±0.250	172.800±0.250	0.670±0.100	0.089±0.001
Creep (g mi^{-1})	5	0.131±0.0020	253	47.740±2.470	5314.0 ±207.000	14.600±1.300	3.879±0.330
Transient (g mi^{-1})	8	2.820±0.0017	668	20.930±0.980	3227±173.000	5.400±0.390	0.500±0.277
Cruise (g mi^{-1})	5	23.530±0.1250	2083	21.250±0.530	1960±105.000	1.950±0.100	0.313±0.040

a. N: number of tests
b. NA: Not applicable

Table 4.5 provides a summary of total mass emissions for NO_X, CO, CO_2, and THC. The total NO_X mass emissions, corrected for altitude, were extremely close for both trips leaving Riverside. Emission factors for NO_X were approximately 39.26 and 29.61 gm km^{-1} for the uphill and downhill trips, respectively. MEL was found suitable to monitor on-road, real-world emissions. Similar trips under different periods of congestion allows for evaluation of the effect of operating mode on total emission rate.

Table 4.5 Total mass emissions of NO_X, CO, CO_2 & THC (Riverside and Victorville) with C15 engine

City		NO_X (g)	CO (kg)	CO_2 (gm)	THC (gm)	Fuel (ml/sec)
Riverside	Trail 1	1223.00	119.30	111.00	17.60	12.30
Victorville	Trail 1	1208.00	123.20	101.00	21.40	12.40
Victorville	Trail 1	865.80	81.90	96.00	12.90	8.40
Riverside	Trail 2	969.70	95.20	93.00	14.60	9.40
Trip distance =85.615 km						

Emission factor for NO_X measured on the road was much higher than both the certification value and EMFAC estimates. A consequence of such underreporting is that inventory and air quality models were not adequately representing environmentally sensitive areas.

Hung et al., (2005) characterised the driving pattern for Zhuhai for traffic emission estimation. They assessed the driving cycle parameters of Zhuhai and Hong Kong as presented in Table 4.6. The driving cycle of Zhuhai was much more different from Hong Kong. Zhuhai had a bigger network catering lighter traffic, resulting in higher driving speeds. The common characteristics of both cities were higher Pa, Pd, and Pd, which indicates that vehicles in both cities had mostly driven in acceleration or deceleration modes and confirmed aggressive driving behaviour in both cities.

Exhaust emissions were significantly related to average speed, average running speed, and positive kinetic energy. Generally, emission factors of exhaust pollutant (CO, HC, and NO_X) are higher at lower speeds and lower in the intermediate speed range. Low average speed operation generates high emission of CO and HC because of the inefficient fuel usage, fuel combustion, and operation of emission control systems. For high-speed operation, high power is required. NO_X is found in higher quantities at higher speed because formation of NO_X is highly sensitive to engine temperature. It was also noticed that emission factors were higher at greater Positive Kinetic Energy with same vehicle (Table 4.7)

Table 4.6 Mean value of the driving parameters for different driving cycles

City	V1 (km h^{-1})	V2 (km h^{-1})	A (ms^{-2})	D (ms^{-2})	C (s)	Pi (%)	Pa (%)	Pc (%)	Pd (%)	M	RMS (ms^{-1})	PKE (ms^{-1})
Zhuhai	29.90	36.30	0.51	0.61	122.50	17.80	37.50	13.20	31.60	21.10	0.60	0.38
Hong Kong	15.50	21.70	0.55	0.59	50.58	31.40	30.90	9.10	28.60	5.90	0.67	0.37

Table 4.7 Driving characterising parameters emission factors and fuel consumption

	Driving cycle parameters [a]							Vehicle emission and fuel consumption [b]			
City	V1 (km h^{-1})	V2 (km h^{-1})	A (ms^{-2})	D (ms^{-2})	Pi (%)	RMS (ms^{-1})	PKE (ms^{-1})	HC	CO	NOX	Fuel (L 100 km^{-1})
Zhuhai	34.10	42.30	0.59	0.69	17.90	0.64	0.34	0.25	2.98	0.97	10.11
Hong Kong	32.10	41.90	0.77	24.70	24.70	0.89	0.61	0.55	8.56	1.62	11.24

(a) Milkins and Watson 1983, (b) Watson 1995

4.5 Comparison of emission factors in passenger cars and motorcycle

Pierre, et al., (2004) investigated the effect of motorcycle engine technology upon physical properties of nanoparticles. In terms of mass, the pre-Euro 1 moped equipped with a 2-stroke engine emitted a significant amount of particulate matter more than the advanced vehicles close to the Euro 4 limit for diesel passenger cars (0.025 gm km^{-1}). The chemical compositions of these particles were obviously very different from those emitted by diesel engines. For 4-stroke engines, the particulate emissions levels were very low and do not significantly diverge from those of modern gasoline passenger cars. The engine technology had a strong influence on the properties of the particulate emissions from 2-stroke mopeds. The mass/size distribution of particulates emitted by these vehicles exhibited a peak in the range of about 200-300 nm (aerodynamic diameter). For the moped equipped with a direct injection engine, the distribution was shifted towards smaller diameters.

Vasic and Weilemann (2006) compared real-world emissions of CO, HC, NO_X and CO_2 from two-wheelers and passenger cars. A chassis dynamometer test bench was used in a climate chamber (Schenk 1500 GS200 for cars and Siemens IP-23 for two-wheelers). During all the tests presented, the temperature in the chamber was kept at a constant 23 °C with a relative humidity of 60%. A speed fan was placed in front of the vehicles to simulate the cooling air stream from real driving. The volume flow rate of the diluted exhaust gas was controlled through the CVS for vehicles.

The usual emission testing setup for cars or trucks was followed. CO was used to calculate fuel consumption. In addition to the bag measurements, the diluted exhaust gas and several other signals such as tailpipe temperature, lambda and engine speed were recorded continuously at a rate of 10Hz for detailed analysis. Several comparisons showed that the powered two-wheelers on the market in 2001 showed significantly higher emissions of all pollutants except CO_2 than gasoline-powered passenger cars from the same sales period (Figure 4.6). Whether in a direct comparison of mean unit emissions (in gm/km), mean yearly emissions (in kg/vehicle/year), or fleet emissions (in tons/ year) the two-wheeler HC and CO emissions were significantly, higher. In addition, the NO_X contribution of the motorcycle fleet was roughly one-fifth that of the car fleet. Overall, emissions from the motorcycle fleet were thus not negligible.

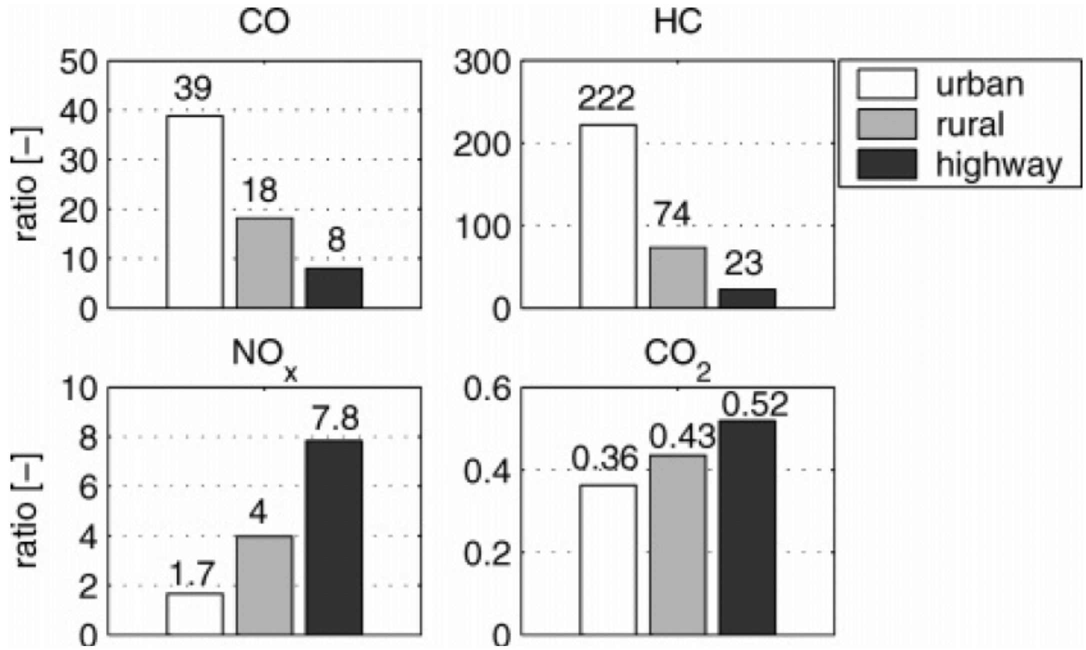


Figure 4.6 Ratio of mean unit emissions (gm/km) from two wheelers & passenger cars

Alvarez et al., (2009) assessed the real-world performance of modern pollutant abatement systems on motorcycles. The current statutory pollutant emission limits (Euro-3) for motorcycles entail the use of modern emission abatement systems such as three-way catalytic converters. To determine the quality of implementation of these new systems in different driving situations such as real world driving, a test bench series was carried out with a sample of 10 motorcycles of state-of-the-art certification category Euro-3. Emission factors of regulated pollutants and CO_2 were presented based on the statutory driving cycle, the latest version of the real-world cycle (WMTC) and the real-world Common ARTEMIS Driving Cycle (CADC). The results of the statutory driving cycle showed that 7 out of 10 motorcycles failed to comply with the present emission limits. The results of both real world driving cycles confirmed the notable emissions of HC in urban and NO_X in motorway driving conditions. CO emissions in motorcycles with small displacement increase significantly in the urban and extra-urban sections of the CADC, which had a more dynamic velocity profile than the equivalent WMTC.

Although pollutant emissions of motorcycles demonstrated a marked improvement compared to earlier certification classes, they clearly exceed the emission levels of modern light gasoline passenger cars, especially for CO and HC. The emission measurement of CO, HC, $NO_{X,}$ and CO_2 for Euro 1 motorcycle and certification category Euro-4 (Passenger Car E4) was made with the CADC and WMTC driving cycle (Figure 4.7). The emission performance of both motorcycle samples obtained with different versions of the cycle WMTC were also compared.

Large-displacement motorcycles generally show better pollutant emission performance, especially in real-world urban and rural driving conditions. However, emission levels of CO and HC for motorcycles, for 'the CADC cycle' was appreciably higher than the respective emission levels of gasoline cars, whereas the difference in NO_X emissions was less pronounced. Only NO_X emissions of small-displacement motorcycles in urban driving conditions attained comparable levels to passenger car emissions. The overall calibration of engine management and the design of exhaust after-treatment systems of passenger cars were far more elaborate and thus more effective than the modern motorcycles with regard to minimizing pollutant emissions.

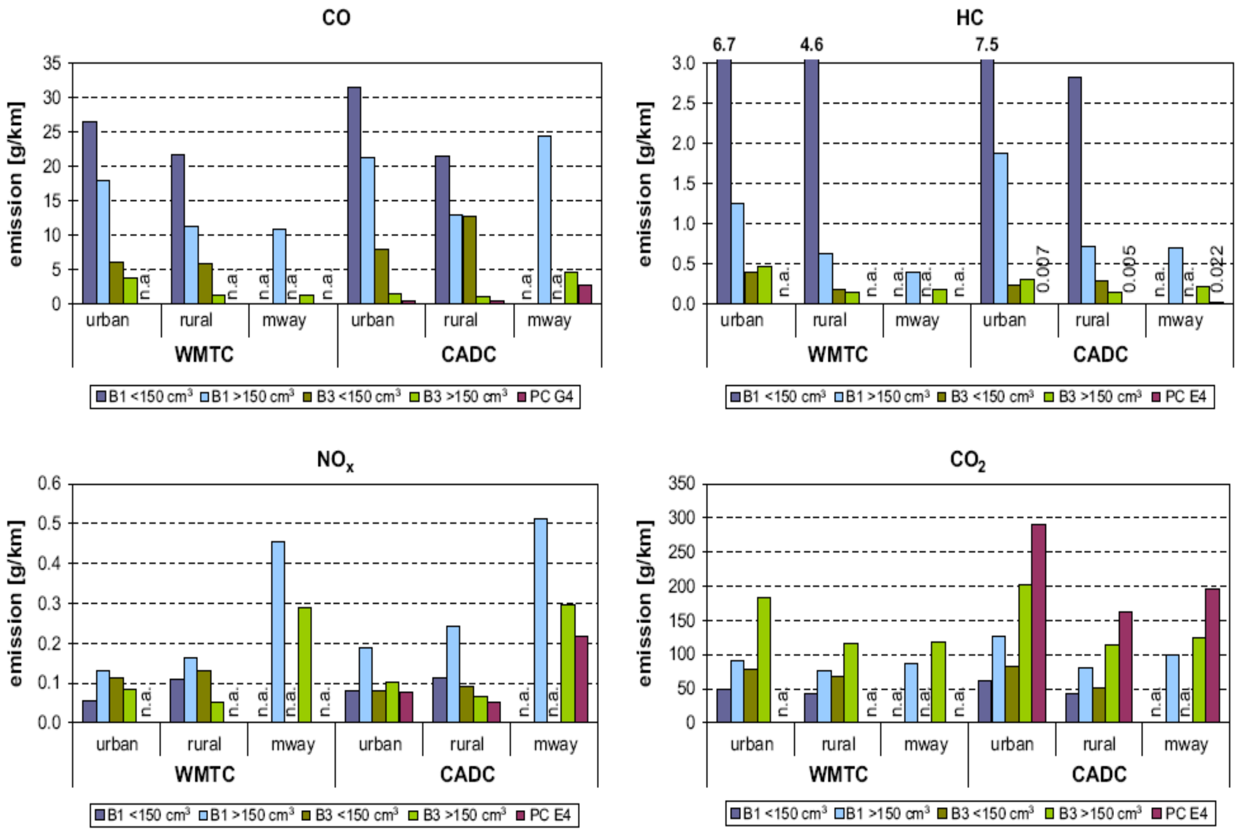


Figure 4.7 Comparisons of real world sample emissions of regulated pollutants and CO_2 with passenger car

4.6 Approaches to estimate the vehicle emission factors

At present four different methods are used to calculate motor vehicle emission factors: driving cycle-based emission factor models; modal emissions-based models; fuel-based approaches; and on-road emissions based models. These are discussed below.

4.6.1 Driving cycle-based models

Driving cycle test data are used as the basis for estimating emission factors in this model type. COPERT 4 driving cycle-based models/TRL emission coefficients is used for regulatory purposes in the UK. EPA and the California Air Resources Board (CARB) respectively use the MOBILE and EMFAC driving cycle for regulatory purposes.

However, all these models have some disadvantages and weaknesses. The emission estimates of both models are based on a limited set of driving cycles. Historically, these driving cycles have been limited to representing real driving conditions, which affect the emission factors (Kelly and Groblicki, 1993; Denis et al., 1994; Barth et al., 1996; NRC, 2000; EPA, 1993; Rouphail et al., and 2000, Barlow, 2001).

The two highway vehicle emission factor models that are used for regulatory purposes do not consider the differences in engine load while calculating the emission factors (Hallmark et al., 2000). When the load on the engine is high, the engine temperature increases significantly. To prevent over-heating and damage to the engine, catalyst vehicles are often designed to operate in fuel-rich mode under high engine loads. It was found that HC and CO emissions increased by almost 20 to 100 times during this type of fuel-rich operation (EPA, 1993). The high engine load may be due to high accelerations, high speeds, positive road gradient, air conditioning operation, or any combinations of these factors. Driver behaviour can also affect the duration of both cold starts and of events leading to high emissions, air-fuel enrichment operation, which in turn have substantial effects on emissions regardless of the total number of vehicle miles travelled. Driving cycle-based models are used for calculating regional emission inventories using aggregate vehicle emissions and activity data. Because of averaging of vehicle emissions and vehicle activity data these models are not suitable for evaluating traffic operational improvements that affect traffic and driving dynamics. For example, improvements in traffic flow (e.g. signal coordination and timing) cannot be evaluated with driving cycle-based models (NRC, 2000).

4.6.2 Modal emissions-based models

In order to estimate effects associated with driving dynamics the modal operation of a vehicle and related emissions need to be analysed. Modal emissions-based models relate emissions directly to the operating mode of vehicles. The operating modes include cruise, acceleration, deceleration and idle (NRC, 2000; Rouphail et al., 2000; Frey et al., 2001, 2003; Tong et al., 2000).

Several research studies have been performed using dynamometers and instrumented vehicles producing second-by-second emissions data to investigate vehicle emissions associated with modal events (Cicero-Fernandez and Long, 1997; NRC, 2000; Rouphail et al., 2000). These studies were found that CO and HC emissions are greatly affected by various acceleration modes even testing on a small set of newer technology vehicles.

Several researchers have developed modal-emissions models by setting up a speed-acceleration matrix in order to characterize vehicle operating modes of idle, cruise and different levels of acceleration/deceleration and determining corresponding emissions (West et al., 1997). According to Barth et al., (1996), the problem with such an approach is that it does not properly handle other variables that can affect emissions, such as road grade or use of accessories. Another disadvantage is that the vehicle driving history is not properly considered, as the vehicle emissions in a given second might be a function of the previous second is speed and acceleration (NRC, 2000).

Another type of modal-emissions based model is based on emission mapping of engine. This approach has been employed since the 1970s for some fuel economy models. The conceptual approach is to translate real-time speed and route information into instantaneous vehicle rpm and load parameters, then use an engine map to look up the instantaneous emission rates for the specific rpm and load conditions and continuously integrate the instantaneous emission rates to estimate the total emissions from a given set of vehicle activities. In developing engine maps, vehicle mileage accumulation is not taken into consideration. Another weakness is that emissions occurring under transient conditions may not be adequately represented by the emissions map that is derived under steady-state conditions. Mapping type models have been developed by LeBlanc et al., (1994), and Shih et al., (1997).

4.6.3 Fuel-based models

In the fuel-based method, emission factors are normalized to fuel consumption and expressed as grams of pollutant emitted per gallon of gasoline burned instead of grams of pollutant per mile. In order to obtain overall fleet-average emission factors, average emission factors for subgroups of vehicles are weighted by the fraction of total fuel used by each vehicle subgroup. The fleet-average emission factor is multiplied by regional fuel sales to compute pollutant emissions (Singer and Harley, 1996). The fuel-based approach is amenable to the use of emissions data collected for on-road vehicles using either remote sensing or tunnel studies, as opposed to relying on laboratory tests in the driving cycle approach. Therefore, this approach may yield a key benefit of being more representative of on-road emissions. Emissions are calculated by vehicle class by applying the multiplication separately for each class. The accuracy of a fuel-based model depends on how well the vehicles and driving modes from which emission factors were measured represent the entire area under study. The accuracy of the age distribution used to weight emissions data from each vehicle model year is another important consideration.

4.6.4 On road emissions data based models

On-road emissions data is obtained by using Remote Sensing Device (RSD) alternatively, on-board instrumentation. Remote sensing devices uses infrared (IR) and, in some cases, ultraviolet (UV) spectroscopy to measure the concentrations of pollutants in exhaust emissions as the vehicle passes a sensor on the roadway. Some applications of RSD include (a) monitoring of emissions to evaluate the overall effectiveness of inspection and maintenance programs (b) identification of high emitting vehicles for inspection or enforcement purposes and (c) development of emission factors. The major advantage of remote sensing is that it is possible to measure a large number of on-road vehicles (e.g., thousands per day). The major disadvantages of remote sensing are that it only gives an instantaneous estimate of emissions at a specific location, and it cannot be used across multiple lanes of heavy traffic. Furthermore, remote sensing is fair weather technology. Variability in vehicle emissions could be because of variation in facility (roadway) characteristics, vehicle location, vehicle operation, and driver. Other factors can be represented and analyzed more reliably with on-board emissions measurement.

This is due to measurements are obtained during real world driving, that eliminates the concern about non-representativeness. These factors are often an issue with dynamometer testing, and at any location, eliminating the sitting restrictions inherent in remote sensing (Unal, 2003).

4.7 Summary and discussions

Estimation of accurate emission factor is important for quantifying the estimates of air pollution. Regulatory emission factors are set up to keep the vehicle emission within limits. Continuously stricter emission norms such as Euro 1, Euro 2, Euro 3, and WMTC have been implemented for motorcycles since 1999. Those emission factors are standardized based on the repeated measurement of emissions on different driving cycles, different loadings, and temperatures on different type of engines.

In the UK, British Standards are in place to measure the emission in laboratory on a chassis dynamometer. The DMRB, COPERT III and COPERT IV are used for emission estimates under regulated driving cycles. However, in the absence of characteristics of local driving conditions these standards would be of limited use.

The results from literature review shows that emissions are significantly affected by driving modes. Low average speed operation generates high emissions of CO and HC because of ineffective fuel usage, fuel combustion, and operation of emission control systems. At high-speed operation, high power is required, and therefore NOx emissions increase because formation of NOx is highly sensitive to engine temperature. Few studies revealed that in general emission factors of CO, HC and NOx for motorcycles were higher than cars.

Four methods for emission measurements are (a) laboratory based methods on chassis dynamometer using different driving cycle (b) on-road emission measurement using remote sensing (c) onboard emission measurement and (d) emission data from secondary sources such as inspection and maintenance of vehicle data — are in practice. In our study, methods (a) and (c) have been used to investigate emissions in real world driving in Edinburgh. In some studies, differences in on-road real-world and laboratory emissions were found.

CHAPTER 5 REVIEW OF MICROSIMULATION TRAFFIC MODELS

5.1 Introduction

Traffic micro-simulation models are computer models, where the movements of individual vehicles travelling around the road networks are determined by using simple car following, lane changing and gap acceptance rules. They are becoming increasingly popular for the evaluation and development of road traffic management and control systems. Traditional models provide an aggregated representation of traffic, typically expressed in terms of total flows per hour. In such models, all vehicles of a particular group obey the same rules of behaviour. By contrast, micro-simulation models provide a better, and 'purer', representation of actual driver behaviour and network performance (Druitt, 1998). This has the ability to model complex highway junctions and congested networks, and at the same time provide a visual representation of the proposed effects on traffic operations.

Micro-simulation is suited to the development, testing, and evaluation of intelligent transportation systems (ITS). Many such systems interact with individual vehicles. Responsive signal control, public transport priority and ramp metering systems react to vehicles approaching junctions. Dynamic Route Guidance systems supply specific information to individually equipped vehicles. Intelligent Cruise Control system adjusts the speeds of equipped vehicles. Therefore, to assess the potential benefits of using ITS, it makes sense to use an assessment tool that is capable of modelling interactions at the level of individual vehicles. Micro-simulation can be used to develop new systems and improve their effectiveness. They can readily estimate the impacts of a new scheme by producing outputs on a wide range of measures of effectiveness. Many of these impacts, such as the amount of pollution emissions, and instantaneous driving cycle, are often difficult to measure in the field in absence of proper measurement equipment. Micro-simulation models can simulate/represent individual driver behaviour;

therefore, it has been used for motorcycle driving simulation as essential part of assessment in this study.

Construction of the driving cycle depends on changes in a complex pattern of speed-time sequences, which can be affected by any change in traffic management schemes, engine size, driver behaviour, road types, trip length and changes in acceleration and deceleration patterns. Several techniques, such as chase car methods, field survey questionnaires, instrumentation of motorcycle and follow-up of motorcycle have been used for collecting the speed-time sequence for development of the driving cycle (Chen et al., 2003; Hung et al., 2007; Shafiepour and Kamalan, 2005). These techniques are expensive and difficult to operate in the field. Recent development in traffic simulation tools such as PARAMICS (Duncan, 1995), AIMSUN-2 (Barcelo et al., 1996) and VISSIM (Fellendorf and Vortisch, 2001) have been successfully used in understanding real-world traffic scenarios in a cost-effective and easy manner. The rapid growth of intelligent transportation systems provides online measurement data to users. Intelligent cruise control systems have sensors to measure speed and distance of the preceding car. Calibration of the simulation is also possible with the aid of the available database of car-following models (Brockfeld et al., 2005).

Several traffic simulation models have been developed for different purposes over the years. In order to validate the simulation models as effective and appropriate tools, many studies have contributed to simulator evaluation. For example, Bloomberg and Dale (2000) compared the VISSIM and CORSIM Traffic Simulation Models and concluded that overall, CORSIM and VISSIM have many similarities. Xiao et al., (2005) developed a comprehensive procedure for selecting a microscopic simulator AIMSUN and VISSIM based on qualitative and quantitative evaluation. In addition, VISSIM software was well calibrated and validated using measurement data obtained from a German freeway and a US freeway, where driver behaviour as well as traffic regulations were substantially different (Fellendorf and Vortisch, 2001).

These are the evidence that simulation tools based on the psychophysical car-following model can reproduce traffic flow very realistically under different real-world conditions. Therefore, in this study, VISSIM simulation tools have been used to model local traffic situations taking into account driver behaviour. As air pollution problems attract more and more attention all over the world, many researchers have attempted to incorporate traffic behaviour that affects emission factors into traffic control strategies.

This chapter reviews the different types of micro-simulation systems, methods of calibration and validation, microscopic traffic simulation models, microscopic motorcycle traffic simulation, methods of data collection and application of microscopic traffic simulation models.

5.2 Types of micro-simulation model

5.2.1 Introduction

The development of car-following and lane-changing rules spawned the development of many early micro-simulation models Gipps (1981, 1986). In recent years, micro-simulation models have been increasingly used to aid studies of a wide range of transportation systems (e.g. Urban Traffic Management and Control System Development [Fox et al., 1995; Scemama et al., 1996], Motorway Management System Development, Micro-simulation validation [Druitt, 1998], Adaptive Signal Control System Evaluation, [Fox et al., 1998], LRT Priority System Development). Alger et al., (1997) reviewed several micro-simulations models — for example, AIMSUN-2, CORISIM, DRACULA, VISSIM etc. — that are listed in Table 5.1, which provides an overview of the most widely used micro-simulation models. Models such as DRACULA, PADSIM, and PARAMICS were developed in UK, while other simulation models such as VISSIM and CORISIM were developed outside the UK, although they are widely used in the UK.

Table 5.1 Summary of the most widely used micro-simulation models

Model	Organisation	Country	Purpose	Location	Emission Model	Lateral behaviour modelling for bike
AIMSUN-2	Universitat Politècnica de Catalunya,	Barcelona Spain	Traffic Management Scheme on Environmental cell,	Dublin, Minneapolis, Dutch cities (Maastricht, The Hague, Eindhoven, etc.)	Yes	No
CASIMIR	Institute National de Recherche sur les Transports et la Sécurité	France	Fixed-time algorithm and three adaptive control algorithms	UK	No	No
CORSIM	Federal Highway Administration	USA	Grade separated expressways and interstate freeways, modelling	Stockholm	No	No
DRACULA	Institute for Transport Studies,	University of Leeds UK	Applying the model in the evaluation of real-time management strategies	East of Leeds	Yes	No
FREEVU	University of Waterloo, Department of Civil Engineering	Canada	Freeway design and analysis	US	No	No
NEMIS	Mizar Automazione, Turin	Italy	Standardisation of the interface between the micro-simulation model and external ITS applications	European Cities (Turin, Alessandrai, Salerno, Gothenburg and Leeds)	Yes	No
PADSIM	Nottingham Trent University – NTU	UK	Micro-simulation model and external ITS applications	Australia, UK	No	No
PARAMICS	SIAS Ltd (The Edinburgh Parallel Computing Centre and Quadstone)	UK	Traffic impact of signal, ramp, ramp meters, loop detectors linked to variable speed signs, VMS and CMS signing strategies	UK, USA, Europe	Yes	No
SISTM	Transport Research Laboratory,	Crowthorne, UK	Study motorway traffic in congested conditions	UK	No	No
ARTEMiS	University of New South Wales, School of Civil Engineering	Australia	Evaluate various traffic scenarios and alternative solutions to a variety of traffic problems, including Intelligent Transport Systems	Australia	No	No
VISSIM	University of Karlsruhe, Germany	Germany	Comparison of junction's lternatives, Design, test, and evaluation of vehicle-actuated signal control operations. Capacity analysis of bus priority schemes	UK, US, Germany	Yes	Yes
VISUM	University of Karlsruhe, Germany	Germany	Signal control, transit operators, city planners and researchers to evaluate the influence of new control and vehicle technologies	UK,US, Germany	No	Yes

From the review of the micro simulation software (Table 5.1 and Appendix 5.1), it can be concluded that VISSIM software is the most appropriate available option to carry out this current study. This is mainly because of the availability of emission module into VISSIM as well as the availability of two wheels vehicle-type, which is needed to create a motorcycle vehicle-type and model its lateral and longitudinal movement. This is crucial in order to be able to replicate motorcycle driving behaviour and its driving cycle. The detail of VISSIM is presented below.

5.2.2 VISSIM

VISIM is a macroscopic transportation model developed by PTV AG, Germany, for transportation planning, travel demand modelling and network management. It can be used to model both public and private transportation modes. Internally VISIM is comprised of several modules.

The results obtained from VISSIM are used to define optimal vehicle actuated signal control strategies, test various layouts and lane allocations of complex intersections, test the location of bus bays, test the feasibility of complex transit stops, test the feasibility of toll plazas, and find appropriate lane allocations of weaving sections on motorways. VISSIM is coupled with micro-scale decentralized controllers of various signal control manufacturers to test their control strategies in detail before they are implemented. VISSIM is a multipurpose simulator used by technical staff at cities responsible for signal control, transit operators, city planners, and researchers to evaluate the influence of new control and vehicle technologies. Vehicles follow each other in an oscillating process. As a faster vehicle approaches a slower vehicle on a single lane, it has to decelerate. The action point of conscious reaction depends on the speed difference, distance, and driver-dependent behaviour. On multi-lane links, vehicles check whether they improve their speed by changing lanes. If so, they seek acceptable gaps on neighbouring lanes. Car following and lane changing together form the traffic flow model that is the engine of VISSIM (VISSIM User Manual, 2008).

(a) Behaviour Modelling in VISSIM

VISSIM uses the psychophysical driver behaviour model developed by Wiedemann (1974). The basic concept of this model is that the driver of a faster moving vehicle starts to decelerate as he reaches his individual perception threshold to a slower moving vehicle. Since he cannot exactly determine the speed of that vehicle, his speed will fall below that vehicle's speed until he starts to slightly accelerate again after reaching another perception threshold. This results in an iterative process of acceleration and deceleration. Stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. The model has been calibrated through multiple field measurements at the Technical University of Karlsruhe. Periodical field measurements and their resulting updates of model parameters ensure that changes in driver behaviour and vehicle improvements are accounted for (VISSIM, 2008).

(b) The 'Wiedemann' Approach

The traffic flow model in VISSIM is a discrete, stochastic, time-step based microscopic model with driver-vehicle-units as single entities. The model contains a psychophysical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. The model is based on the continued work of Wiedemann (Wiedemann, 1974). The basic idea of the Wiedemann model is the assumption that a driver can be in one of the four driving modes as follows:

- Free driving: No influences of preceding vehicles are observable in this mode. The driver seeks to reach and maintain a certain speed, his individually desired speed. In reality, the speed in free driving cannot be kept constant, but oscillates around the desired speed due to imperfect throttle control.
- Approaching: The process of adapting the driver's own speed to the lower speed of a preceding vehicle. While approaching, a driver applies a deceleration so that the speed difference of the two vehicles is zero in the moment he reaches his desired safety distance.

- Following**:** The driver follows the preceding car without any conscious acceleration or deceleration. He keeps the safety distance more or less constant, but again due to imperfect throttle control and imperfect estimation the speed difference oscillates around zero.
- Braking**:** The application of medium to high deceleration rates if the distance falls below the desired safety distance. This can happen if the preceding car changes speed abruptly, of if a third car changes lanes in front of the observed driver.

For each mode, the acceleration is described in terms of speed, speed difference, distance and the individual characteristics of driver and vehicle. The driver switches from one mode to another as soon as he reaches a certain threshold that can be expressed as a combination of speed difference and distance. For example, a small speed difference can only be realized in small distances, whereas large speed differences force approaching drivers to react much earlier. The ability to perceive speed differences and to estimate distances varies among the driver population, as well as the desired speeds and safety distances. Because of the combination of psychological aspects and physiological restrictions of the driver's perception, the model is called a psycho-physical car-following model. The following sections describe the various behaviour parameters in VISSIM.

(c) Wiedemann 74 Model Parameters

This model is an improved version of Wiedemann's 1974 car-following model. The following parameters are available:

- Average standstill distance (ax): It defines the average desired distance between stopped cars. It has a fixed variation of ±1m.
- Additive part of desired safety distance (bx_add)
- Multiplicative part of desired safety distance (bx_mult) — affects the computation of the safety distance.

The distance d between two vehicles is computed using this formula:

$$d = ax + bx$$

Where ax is the standstill distance.

$$bx = (bx\_add + bx\_mult * z) * \sqrt{v}$$

Where v is the vehicle speed (ms^{-1}). Z is a value of range [0, 1], which is normally distributed around 0.5 with a standard deviation of 0.15. These are the main parameters that affect the capacity flow. In addition, Wiedemann's 1999 car following model for driver behaviour in VISSIM is suitable for freeway traffic.

5.3 Review of studies on microscopic traffic emission models

Microscopic modelling of traffic flow and driving mode plays an essential part in the assessment of the potential of, and implementation of new traffic demand management measures that significantly affect the driving profile over an area. At a microscopic level, the driving cycle (speed fluctuation) is the most important factor influencing emissions (Jensen 1995, Andre 2004). Currently, significant effort is being devoted to the development of models that can account for speed fluctuations and model vehicle emissions more realistically (Matzoros and Van Vliet, 1992, EPA 1997, Williams and Smith, 1998). Speed fluctuations and vehicle emissions are controlled by signal timing improvement in congestion management practices. The benefits of improved signal timing for reduced fuel consumption are well documented. Unal et al., (2003) investigated effect of arterial signalisation and level of service on measured emission using empirical approach based on real-world on-road vehicle emission measurements in Cary, North Carolina. They did modal analyses of the data that indicated that emission rates were highest during acceleration and tend to decrease, in descending order, for cruise, deceleration and idling.

The EPA's current Mobile model, California's EMFAC model and the UK Design Manual for Roads and Bridges method (DMRB, 2008) rely only on average vehicle speeds derived from average driving cycles. While these embody various levels of acceleration within the driving cycle, they do not allow the evaluation of policies that can result in changes in the level and quantity of accelerations. VISSIM traffic micro-simulation models providing second-by-second vehicle behaviour was combined with a modal emissions database, such as CMEM (developed by Barth et al., 2000) (Fellendorf, 2001).

In another study, Stathopoulos and Noland (2003) investigated the induced travel and emission from 'traffic flow improvement projects' using the combined model — VISSIM with a modal emissions model (CMEM) — to evaluate CO, HC, NO_X and CO_2 emissions as well as fuel consumption. They found that the introduction of road humps was not supposed to result in air quality improvement. Modelling of a real network with road humps was developed to adapt the integrated framework to evaluate the emissions impact.

In another application of the micro-simulation approach Li et al., (2004) analysed the impacts of traffic signal timing plans on the reduction of delays and traffic emissions at the isolated signalised intersections in Nanizang city. They calculated the Performance Index (PI) for optimisation of signal time to minimize the delay time of vehicles and emissions. They optimised the green time based on PI, ultimately giving lesser emissions.

Marsden (2001) developed an approach to microscopic road traffic exhaust emission modelling that could operate on-line in real-time and off-line as a strategy assessment tool. The model used input from the SCOOT demand-responsive traffic control system to identify vehicle type and estimate speed of vehicles as they passed over the inductive detector loops located toward the upstream end of each link within a SCOOT network.

Correlation between emission modules and driving modes were developed by (Table 5.2). An exploratory application of this model was improved for detection and maintenance of high-emitting vehicles, which were responsible for significantly elevating overall CO emissions, particularly during idling and acceleration periods, which predominate near the stop-line where pedestrian exposure may be highest. Macroscopic traffic models that are based on average speed and flow levels do not adequately model the details of the effects of new technologies on driving patterns. Therefore, the importance of driving modes and acceleration to exhaust emissions was demonstrated by modelling these factors.

Table 5.2 Correlation between emission modules and driving modes

Pollutant	Acceleration (%)	Deceleration (%)	Cruise (%)	Idle (%)
CO	0.17	0.12	0.10	0.07

Hallmark et al., (2000) assessed the impact of traffic signal timing improvement on traffic emissions. Qu et al., (2003) analysed the traffic emissions along a freeway corridor under different speed limit scenarios. Zietsman et al., (2005) provided a comparison of light duty gasoline vehicles' exhaust emissions under two different situations of stop-restart and idling at intersections, on traffic emissions, noise and fuel consumption in China. In another study, Feng et al., (2002) evaluated the impact of electric toll collection (ETC) systems on controlling vehicles' emissions.

Zhang et al., (2006) utilized the Portable Emission Monitoring System (PEMS) to collect the field vehicle emission data. They analysed the emission characteristics of different emission species for different vehicles' turning movement at intersections and calculated the ratio of emissions for each turning movement on the road. Kun and Lei (2007) developed an integrated microscopic traffic-emission simulation platform for estimating vehicle emissions, which can instantaneously capture vehicles' modal activities, and quantify the relationship between motor vehicles' exhaust emissions and vehicles' operating modes. The case study of urban road networks in Beijing with large traffic flows was made to illustrate that vehicles' emissions were strongly dependent on their operating modes, especially during acceleration. Furthermore, different instantaneous speeds and accelerations resulted in different traffic emissions. The impacts of different traffic control strategies on traffic emissions were analysed. It was observed that setting an exclusive bus lane improved the traffic operation of the roads in the study network, and reduced the CO, HC, and NO_X emissions of buses.

In the UK, Park et al., (2001) developed a microscopic model of air pollutant concentrations. Detailed speed fluctuations in the flow of traffic were presented in the approach that was applied to a local network in Maidstone, Kent. A stochastic microscopic traffic flow simulation model (VISSIM), an existing speed-based emission database (MODEM) and a Gaussian dispersion model were combined. Simulated results were compared with a macroscopic model of air pollutant concentrations (DMRB method) and roadside pollutant measurements. Their results showed a reasonable comparison with the DMRB results and with the trends in measured pollutant concentrations. In this current study, a similar approach has been developed for emission measurement. The TRL emission factors have been used on real world onboard driving data (Chapter 11).

5.4 Simulation modelling of motorcycles traffic flow

Mixed-traffic flow is composed of standard vehicle types such as passenger cars, buses, and trucks, as well as non-standard vehicles such as motorcycles and bicycles. Normally, the behaviour of standard and non-standard vehicle types are different, therefore it becomes difficult to model mixed-traffic flow. In the past, mixed-traffic flow phenomena have been described by statistics and simulation of the mixed-traffic flow using some microscopic behaviour principles. Faghri (1999) created an equation of vehicle following, which was applicable to the cases of car-bicycle, bicycle-car and bicycle-bicycle following. Oketch (2000) incorporated car-following rules and lateral movement to model mixed-traffic flow, where lateral movement was governed by fuzzy logic rules. Chaos theory and artificial neural network theory were also used to develop a mixed-traffic flow mode (Li, 2004).

The movement of motorcycles is a two dimensional movement which includes longitudinal and lateral movement. The longitudinal movement makes motorcycles go forward and the lateral movement makes motorcycles take up appropriate positions for overtaking. A motorcyclist gets longitudinal gaps, while accelerating its speed and managing to move laterally in less gap distance during the lateral movement. The motorcycle traffic flow is influenced by driver characteristics, vehicle interactions and the external environment. Cho and Wu (2004) modelled the motorcycle traffic flow taking account of all these parameters for urban area. They proposed a model, which includes: (a) driver characteristics: desired speed, the maximum acceleration and deceleration of a vehicle (b) external environment: the width of the motorcycle lane and markings (c) the vehicle interactions include: longitudinal and lateral movement models. A link was chosen for motorcycles, which was not influenced, by signals or intersections.

5.4.1 Motorcycle driving behaviour

Driver behaviour affects the traffic flow and its dynamics, for example, motorcycle has higher power to mass ratio, which causes more acceleration rate in less time. Driving behaviour models describe vehicles' movements under different traffic conditions. These models include speed/acceleration models and lane changing models. These models are an important component of microscopic traffic simulators. They are also important to several other application areas, such as safety studies and capacity analysis, in which aggregate traffic flow characteristics may be deduced from the behaviour of individual drivers (Hidas, 2005).

Typically, in the literature, these models have been developed independently and used parallel to microscopic simulation models. Toledo (2007) developed a framework for driving behaviour modelling that integrates the various decisions, such as acceleration, lane changing and gap acceptance. Driver decision on acceleration, lane changing, and gap acceptance change from vehicle to vehicle. Normally, at intersections such decisions are critical for motorcycles. The time needed for a vehicle to proceed through an intersection varies from one vehicle to another. For example, a bus takes longer time to drive through an intersection than a car and hence impedes other users of the intersection more than a car. In order to account for this variability in impedance on other users, traffic volumes are described in passenger car units (pcus) rather than vehicles.

Based on data from Bangkok, May and Montgomery (1986) reported that motorcycles crossing the stop line in the first 6 seconds of effective green time impose little impedance on other traffic, since they wait at the front of the queue and accelerate faster than other vehicles at the start of the green period. They suggested that a pcu value of 0 should be used for motorcycles of this type (other authors have even suggested that a negative pcu value could be used). They found that motorcycles crossing the stop line later in the cycle had a pcu value that varied from 0.53 to 0.65, depending on the lateral positioning of the motorcycle and its eventual turning movement.

Powell (2000) created a model to represent motorcycle behaviour at signalised intersections. The model was tested against video data of motorcycles collected at intersections in Indonesia, Malaysia and Thailand, where the proportion of motorcycles is high (up to 70%), and predicted the number of motorcycle passing per cycle with a high degree of accuracy. The motorcycle behaviour factor was important in predicting the number of motorcycle passing the signal at the cross line. Factors were both temporal (inputs for the amended first order macroscopic model) and spatial (average lane width, number of lanes and number of buses and trucks per lane per cycle). The importance of the storage space at the front of the queue was noted and included within the model.

Lee (2007) developed an agent-based model to simulate motorcycle behaviour in mixed traffic flow on a section of the road in London. The mathematical models were developed for describing the motorcycle behaviour implemented in this simulator. Applications of those simulators showed that it was possible to carry out policy tests using the simulator and was a powerful tool for conducting a study on mixed traffic flow containing motorcycles. However, this study was limited to mid block section and was unable to carry out simulation for longer sections of multiple intersections.

Chakroborty et al., (2004) developed a comprehensive microscopic model of driver behaviour in uninterrupted traffic flow. Rongviriyapanich and Suppattrakul (2005) analysed the effects of motorcycles on traffic operations at signalised intersections and a mid-block section of an urban road. Data collection was done at two intersections, one with motorcycle queue storage and the other without. At mid-block, Passenger Car Equivalent (pcu) of motorcycles at different traffic volume and proportion of motorcycles in traffic stream were determined. It was found that the pcu of motorcycles consistently decreases with the share of motorcycles in total traffic.

Many studies have been carried out on different aspects of motorcycles such as pcu, motorcycle traffic flow, motorcycle behaviour at junction (e.g. motorcycle crossing the stop line) and at road sections. However, not much research to date has attempted to simulate motorcycles driving cycles in micro simulation models taking into account local driving conditions.

5.5 Data collection approaches in micro-simulation modelling

Measurements of traffic speed and travel times are needed for a wide range of practical applications (also development of simulated driving cycle). Road user's speed in traffic environments is very informative and thus widely used for driver and behavioural studies parameters. Methods used for data collection for input to micro-simulation study are given below.

(a) Local detectors approach

The current state-of-the-practice for data collection regarding traffic speeds relies mainly on local detectors that measure the speed at a specific point along the roadway. One of the most widely used technologies for this purpose is magnetic loop detectors, installed underneath the roadway surface. Due to the cost of installation and maintenance of local detectors, they are typically installed only on a relatively small portion of the roadway system, thus providing limited coverage of the entire transportation network. Most of the conventional instruments (e.g. radar guns or loop detectors) can provide only spot measurements of speed (Gera, 2007).

(b) Video filming approach

In addition, in an urban environment there are many traffic interruptions, particularly at intersections. These interruptions cause delays that are not depicted by measuring speeds at any specific point along the road. An alternative approach is to measure travel times of vehicles along a certain route or route segment. Use of video recordings can help to make such studies. The increased knowledge and experience in video analysis makes it practically possible to automate data collection process, thus allowing collection of continuous (as long as a road user is within the camera's view) speed data with reasonably low time consumption and costs (Almadani, 2003). The main strength of the video recording method is to record everything that happens in the traffic flow. Besides that, video camcorders are comparatively simple and affordable, compared to the cost for driver and petrol in the floating-car method for example. Therefore, the video recording method is employed in this study. Real-world driving data was collected once for the calibration and validation of the results.

A major advantage of video recording is that it can obtain all the trajectories and sizes of the vehicles in a traffic stream objectively. Another merit is that the video footage can be reviewed and examined repeatedly at later times. In addition, it is an un-intrusive and naturalistic observation, which ensures that the normal behaviour can be observed and the data collected are not affected by the presence of researchers. The following are the advantages of video recording methods:

However, extracting data from video footage is an extremely labour-intensive process, which is the main disadvantage of this method. According to Taylor and Young (1988), the analysis process can take up to six times long as the real time recording. Another disadvantage of this method is the limited survey areas, around 200 m (Hidas and Wagner, 2004) to 400 m (Slinn et al., 1998), depending on the resolution of the images and the field of view of the camera. The requirement of an elevated position is also a limitation of this method

(c) Floating-car method

The advantage of the floating-car method is that the data processing is simpler and it can directly collect the useful parameters, depending on the sensors employed. The floating car method can be equipped with a wide range of sensors, including camcorders (for example, as used by Olsen and Wierwille [2001]). Floating-car method has some limitations because the data can only be collected from a limited number of instrumented vehicles. Driver's behaviour under surveillance and limitation of choices in sensor affect the range of data collection. In order to obtain a complete picture of the surroundings, the vehicles need to be well designed and well equipped, making the whole process expensive. Context of the experimental environment should be setup to avoid the surrounding environment (Hidas and Wagner, 2004).

(d)GPS approach

For a small number of occasional needed measurements, dedicated ‘floating vehicles’ can be used. The equipped floating vehicles with GPS can improve the accuracy of the measurements (Byon et al., 2006). Vehicle equipped with differential GPS (DGPS), was used and managed to match its route for 93% of the distance it travelled to examine the ability to meet location accuracy requirements. Equipping vehicles with GPS was feasible mainly when considering specific fleets (Reinhart and Schafer, 2006; Du and Aultman-Hall, 2006). GPS was equipped in trucks, cars and buses to find their routes and evaluate infrastructure performance improvements (Chakroborty and Kikuchi, 2004). GPS data from a fleet of equipped vehicles, typically limited in its size, was found to have limited coverage area in the real world. GPS provides data for specific fleets often have specific travel patterns that may not necessarily representative of the entire population.

(e) Cellular measurements approach

Cellular phones have reached extensive market penetration in many countries. Cellular phones can be used to identify locations, since any cellular service system contains information about the locations of its users over time. Gera (2007) examined the performance of cellular phone service provider for measuring traffic speeds and travel times. Cellular measurements were compared with those obtained by dual magnetic loop detectors. A good match between data was found using the two measurement methods; indicating that the cellular phone-based system is useful for other practical applications, such as advanced traveller information systems, and evaluating system performance for modelling and planning.

The continuous speed data from GPS, however, is more informative since it provides speed-based indicators that can be calculated (e.g. speeds variation over a distance, acceleration, travel time, etc.).

(f) Data collection from secondary sources

Secondary data is the data, which has been collected by individuals or agencies for purposes other than those of our particular research study. It is far cheaper to collect secondary data than to obtain primary data. For the same level of research budget, a thorough examination of secondary sources can yield a great deal of more information than can be collected through a primary data collection exercise.

Whilst the benefits of secondary sources are considerable, their shortcomings have to be acknowledged. There is a need to evaluate the quality of both the source of the data and the data itself. The main problems may be categorised as follows:

Definitions: The researcher has to be careful, when making use of secondary data, of the definitions used by those responsible for its preparation.

Measurement error: When a researcher conducts fieldwork, she/he is possibly able to estimate inaccuracies in measurements through the standard deviation and standard error, but these are sometimes not published in secondary sources. The only solution is to try to speak to the individuals involved in the collection of the data to obtain some guidance on the level of accuracy of the data.

Source bias: Researchers have to be aware of vested interests when they consult secondary sources. Those responsible for their compilation may have reasons for wishing to present a more optimistic or pessimistic set of results for their organisation. It is not unknown, for example, for officials responsible for estimating food shortages to exaggerate figures before sending aid requests to potential donors. Similarly, and with equal frequency, commercial organisations have been known to inflate estimates of their market shares.

Reliability: The reliability of published statistics may vary over time. It is not uncommon, for example, for the systems of the collecting data to have changed over time but without any indication of this to the reader of published statistics. Geographical or administrative boundaries may be changed by government, or the basis for stratifying a sample may have altered. Other aspects of research methodology that affect the reliability of secondary data are the sample size, response rate, questionnaire design, and modes of analysis.

Time scale: Most census take place at 10-year intervals, so data from this and other published sources may be out of date at the time the researcher wants to make use of the statistics[1].

(g) Accuracy of the data

When evaluating data collection methods, the accuracy of the data acquired is an important issue to be considered. However, it is difficult, in general, to compare the accuracy of the data obtained from these categories because the accuracy of the data collected by the floating-car method (may include GPS or cellular-based data) depends on the equipment used. In addition, their purpose of use is limited to vehicles only. Accuracy of the local detector depends on sensor quality and installation efficiency and detector is placed on limited stretch of section. Therefore, the comparison between these approaches cannot be made in this section.

The accuracy of the video recording method depends on the pixel resolution of the video images, so the trade-off between pixel resolution and field of view has to be considered. For example, a telephoto image provides a high resolution but has a limited survey area whereas a wide-angle image accommodates more information but has a limited resolution. Therefore, a camcorder with a higher definition or a larger focal length factor will be more flexible to provide data with higher accuracy. The literature shows that different extents of accuracy, from 0.3 m to 1.3 m, have been reported (Khan and Raksuntorn, 2001; Hasan et al., 2002; Hoogendoorn et al., 2003; Hidas, 2005). Also, data from secondary sources need to be validated by collection of real world data; if the data accuracy can reach such a standard, it should be sufficient for calibrating the models as proposed in Chapter 10.

5.6 Calibration and validation of microscopic simulation model

Simulation modelling is an increasingly popular and effective tool for analysing transportation problems that are not amendable to study by other means. For any simulation study, model calibration is a crucial step to obtain any results from analysis. Therefore, several researchers (Chu, 2004; Oketch and Carrick 2005; Dorothy et al., 2006; Boel and Mihaylova, 2006) have performed calibration and validation of different micro-simulation models. Microscopic simulation models have been widely accepted for evaluation of various transportation system design and traffic operations and management

1 (http://www.fao.org/docrep/w3241e/w3241e03.html Accessed on 2nd December, 2008).

strategies. In that regard, the calibration and validation of simulation models is crucial for an appropriate decision-making process. The key to successful evaluations relies on the validity of the microscopic simulation model.

Chu et al., (2004) developed a calibration procedure for microscopic traffic simulation. They presented a systematic, multi-stage procedure for the calibration and validation of PARAMICS simulation models for network-level simulation in the southern California, responding to the extended use of microscopic simulation models. The calibrated model showed reasonable performance in replicating the observed flow conditions in multiple steps networks. Various components of models were addressed in the model calibration process.

Boel and Mihaylova (2006) developed a stochastic model of freeway traffic at a time scale and of a level of detail suitable for on-line estimation, routing, and ramp metering control. It was aimed to be applied to on-line prediction algorithms and control strategies (such as ramp metering and adaptive routing) for large freeway networks. The freeway was considered as a network of interconnected components, corresponding to one-way road links consisting of consecutively connected short sections (cells). Cell transmission model (Daganzo, 1994) was extended by defining sending and receiving functions explicitly as random variables, and by specifying the dynamics of the average speed in each cell. The macroscopic traffic behaviour of each cell, as well as its interaction with neighbouring cells, was obtained by using simple stochastic equations, which allowed the simulation of quite large road networks by composing many links. The model was validated over synthetic data with abrupt changes in the number of lanes and over real traffic data sets collected from a Belgian freeway.

Oketch and Carrick (2005) calibrated and validated a micro-simulation model in network analysis. Calibration and validation efforts were carried out as part of network analysis of a sub-area in the city of Niagara Falls using the PARAMICS micro-simulation model. Model results were compared to the field data that included not only link traffic volumes and turning movement counts at intersections but also measures of effectiveness such as average travel times and approach queues. Estimation of suitable origin-destination matrices was made which replicated the observed traffic volumes and turning movement counts at selected intersections to the acceptable levels. A modified chi-square statistic test was used to compare the modelled and observed volumes. Further model validation was conducted by comparing modelled and observed measures of effectiveness. It was found that target benchmarks that demonstrated an acceptable match between modelled and observed results were achieved with moderate calibration efforts. However, greater efforts were required to achieve marginal improvements in the accuracy of the model outputs and the ability of the model to predict the measures of effectiveness that largely depended on the closeness of the match between observed and modelled traffic volumes.

Dorothy et al., (2006) developed and validated large-scale microscopic models. Development of reliable large-scale transportation network models for detailed microscopic analysis was a complicated and time-consuming process. They reported a methodology to develop and validate a large-scale network in Columbus, Ohio using VISUM and VISSIM. This validation methodology caused a higher error percentage for links with low traffic volumes and lower error percentage for links with high traffic volumes. Generally, conversion of networks built in one tool to other tools was prone to errors because of software incompatibility and licensing issues.

Fellendorf and Vortisch (2001) validated the microscopic traffic flow simulation model VISSIM, both on a microscopic and a macroscopic level. The VISSIM car-following model was originally designed to model driver behaviour on German freeways. There was no general speed limit on German freeways, but more and more parts of the network, especially the highly congested ones, were limited to 120 km h^{-1}. To validate the lane-changing behaviour, the distribution of the total volume to the single lanes was examined. Both microscopic calibration and macroscopic validation results showed that simulation tools based on the psycho-physical car-following model could reproduce traffic flow very realistically under different real-world conditions. They reported that it was possible but also necessary to adapt the model to the local traffic situation by taking account of national traffic regulations and driving styles. Adaptation of the model was also dependent on microscopic data gathered by probe vehicles equipped with electronic sensors or on macroscopic flow data from measurement. Standardized sets of calibration parameters for VISSIM were available for Germany.

Park and Qi (2005) used VISSIM microscopic simulation model for calibration and validation for a freeway work zone network. Multiple days of field data were collected to consider variability and these days were divided into calibration and validation datasets. Traffic flow characteristics of a freeway network, especially in a work zone, were quite different from those of urban arterial networks. In addition, car following logic used in a freeway network was different from that of arterial network. Twenty-one initial sets of parameters were identified as relevant to the performance of the simulation model and their acceptable ranges. VISSIM parameters were calibrated in order to reproduce, as close as possible, real driving behaviours recorded by an on-board engine management system. Emissions results given by the proposed dual VISSIM-CMEM model for a single vehicle were compared with results obtained when feeding CMEM with experimental speed and acceleration profiles. As mentioned above, review showed the evidence that the developed framework of analysis can provide policy-makers with scientific information on the emissions and fuel impacts of urban transport policy and assist them in the evaluation of external costs to society. These variations are apparent in driving behaviour, in the level of demand, in the intensity of roadside activity, in weather conditions etc. Heterogeneity and randomness are fundamental concepts in traffic micro-simulation models: random values of driver characteristics, vehicle features and so on are drawn in every run of these models from preset distributions or samples; running a model several times with the same inputs will give different outputs.

A Genetic Algorithm (GA) concept was integrated with VISSIM to find the optimal parameter set for the Covington network (Mc Kay et al., 1979). The Latin Hypercube sampling (McKay et al., 1979) toolbox in MATLAB was used to generate 200 scenarios using the initial set of parameters and their ranges. A GA procedure of 10 generations and 20 populations were repeated twice with different starting random seeds. The GA was able to converge to the optimal solution at the beginning generations. The parameter set with the best fitness value was selected for the final evaluation. Traffic data collected on a different day was used for validation of parameter sets obtained from the calibration process. The field travel time was compared to the distributions of one hundred runs using three parameter sets. Field data was a bit outside of the distributions of the calibrated parameters, but much closer to the distribution of GA-based parameters than those of the best-guessed and un-calibrated parameters. This procedure was effective in the calibration and validation of a freeway work zone network.

Hollander and Liu (2008) estimated the distribution of travel time by repeated simulation. The detailed experiments were performed with DRACULA (Liu et. al., 2006) in the city of York, England. For estimation of the distribution of travel time (DTT) it was found useful to calibrate the main parameters that influence the DTT (the calibration parameters are shown in Table 5.3.

This includes four parameters of the gap acceptance model, eight parameters that relate to car and bus acceleration, eight parameters for car and bus deceleration, and a single parameter that stands for the standard deviation of the overall level of traveller demand that were used to calibrate the goodness of fit. Some of the parameters were also used for calibration and validation of the micro-simulation model for driving cycle in our study (Chapter 10).

To evaluate the goodness-of-fit of other sets of parameter values the same number of model repetitions was performed repeatedly. It was found that it is vital to have a sufficiently large sample (i.e. number of days or number of runs) in order to analyse and check the variability between day and between runs to ensure a credible estimate of the objective functions.

Table 5.3 Example of calibration parameters

Calibration parameters	Initial value	Likely range		Feasible Range	
		Min	Max	Min	Max
Normal acceptable gap (s)	3.00	1.00	5.00	0.10	60.00
Minimum acceptable gap (s)	0.50	0.20	2.00	0.10	60.00
Time waited before accepting reduced gap (s)	30.00	20.00	40.00	0.10	600.00
Time waited before accepting minimum gap (s)	60.00	40.00	80.00	0.10	600.00
Mean of car normal acceleration ($m\ s^{-2}$)	1.50	1.00	5.00	0.10	60.00
Coefficient of variation of car normal acceleration	0.10	0.00	0.30	0.00	2.00
Mean of car maximum acceleration (ms^{-2})	2.50	2.00	5.00	0.10	60.00
Coefficient of variation of car maximum acceleration	0.10	0.00	0.30	0.00	2.00
Mean of car normal deceleration ($m\ s^{-2}$)	2.00	1.50	5.00	0.10	60.00
Coefficient of variation of car normal deceleration	5.00	3.50	6.50	0.10	60.00
Mean of car maximum deceleration ($m\ s^{-2}$)	1.50	0.80	2.00	0.10	60.00
Coefficient of variation of car maximum deceleration	0.10	0.00	0.30	0.00	2.00
Demand fluctuation (coefficient of variation of overall demand)	0.10	0.00	0.30	0.00	2.00

5.7 Summary

Construction of the driving cycle depends on changes in the complex patterns of speed-time sequences, which can be affected by any change in traffic management schemes, engine size, and type of driver behaviour, road type, trip length and changes in acceleration and deceleration pattern. The micro-simulation methods are good tools to derive the driving cycle in the absence of field data. This method utilises the data from secondary sources such as city councils and state road departments.

Much research evidence shows that simulation tools based on the psycho-physical car-following model can reproduce traffic flow very realistically under different real-world conditions. Therefore, VISSIM simulation tools have been used to model local traffic situations taking into account driver behaviour in many research studies. Several micro-simulation models (AIMSUN-2, CORISIM, DRACULA, PADSIM, PARAMICS) have been developed in the UK, while others such as VISSIM and CORISIM while used in the UK, were developed elsewhere. VISSIM uses the psycho-physical driver behaviour model developed by Wiedemann (1974). The traffic flow model in VISSIM is a discrete, stochastic, time-step based microscopic model with driver-vehicle-units as single entities. The model contains a psycho-physical car- following model for longitudinal vehicle movements and a rule-based algorithm for lateral movements.

Nevertheless, results from any micro-simulation model need to be calibrated first, and then validated, because micro-simulation models require many small inputs of base data. In addition, it works on empirical relations in the background, therefore 100% accuracy in results cannot be guaranteed. However, the results can be very close to real-world data if the model is repeatedly run by changing the different traffic, driver behaviour and vehicle-related data.

While the chassis dynamometer is the standard method for measuring emissions in the laboratory, it is expensive in nature. Therefore, calculating emissions based on micro-simulation model results can be a reasonable alternative. Emissions results from micro simulation can be obtained using the emission factors and vehicle speeds.

CHAPTER 6 THE DEVELOPMENT OF EDINBURGH MOTORCYCLE DRIVING CYCLE (EMDC)

6.1 Introduction

Development of representative driving cycles is an important part for emission measurement. Therefore, many research studies have been undertaken on this subject as discussed in the literature review (e.g. Simanaitis, 1977; Kent et al., 1978; Kulher and Karsten, 1978; Watson et al., 1982; Wang et al., 1985; Lyon et al., 1986; Andre et al., 1995; Tzeng and Tong et al., 1999; Chen et al., 1998; Booth et al., 2001; Shafiepour and Kamalan, 2005; Tsai et al., 2005; Hung et al., 2007; Kumar et al., 2007).

This chapter details a methodological development of the Edinburgh Motorcycle Driving Cycle (EMDC) in which data collection was carried out using instrumented motorcycles driving through urban and rural areas of Edinburgh. Precautions during field data collection are also discussed. Selection of the testing routes was mainly based on the experience and knowledge of the local traffic conditions encompassing the north–south and east–west routes of the city. Driving data were synthesise to develop the candidate driving cycles. The best cycle was then selected for least cycle length for the routes based on the least sum of the average absolute percentage error (AAPE) between the average and the test cycles

6.2 Route selection

The present study focuses on trips made by commuters on motorcycles within Edinburgh and the surrounding areas. Five different routes were selected (Figures 6.1 and 6.2) including motorways, rural highways and urban roads, which connect the main trunk roads (M8, A90 and A1 and A720) and arterial roads (A7, A701, A702, A70, A900 and A1140) surround and connect the city (Table 6.1). Most of the selected rural roads were single carriageway with the exception of only one routes 002 dual carriageway route (Figure 6.2). Each route starts typically from a residential area and ends at the workplace at Edinburgh Napier University. The trips were made in the morning from the selected residential points and all ended at the work place. The return trips start from the work place and end at the five different residential points in the afternoon and evening. These routes cover most major roads into Edinburgh since the selected routes encompassed north–south and east–west routes in the city.

Table 6.1 Description of the five selected routes

Route description	Connecting routes from Napier	Route nomenclature	Length (km)
Napier to Fife	A720-A8-B701-A90	001	31.00
Napier to Linlithgow	A720-M8-A803	002	29.00
Napier to Penicuik	A701-A702-A6094-A772	003	14.60
Napier to Haddington	A720-A701-A1-A199	004	7.30
Napier to Biggar	A702	005	32.20

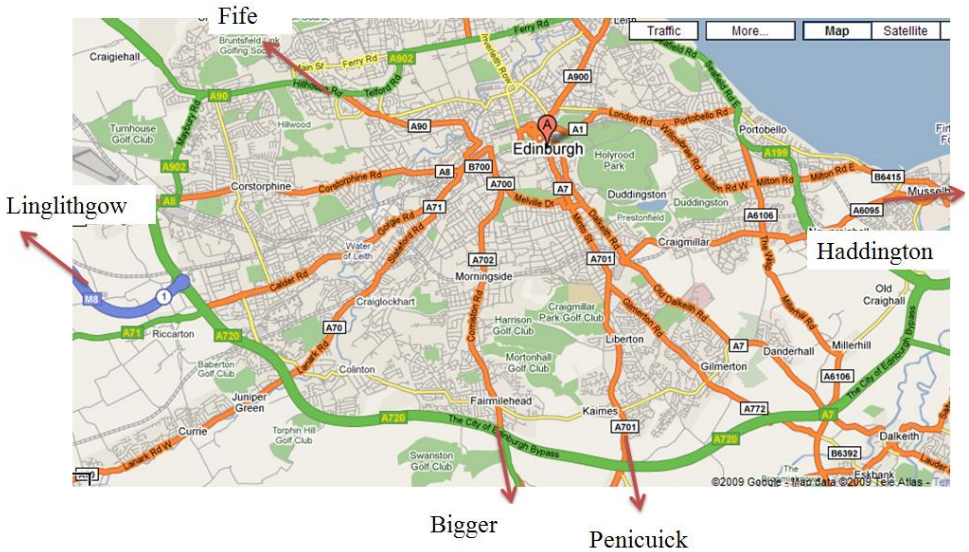


Figure 6.1 The road network map of the study area showing road connection

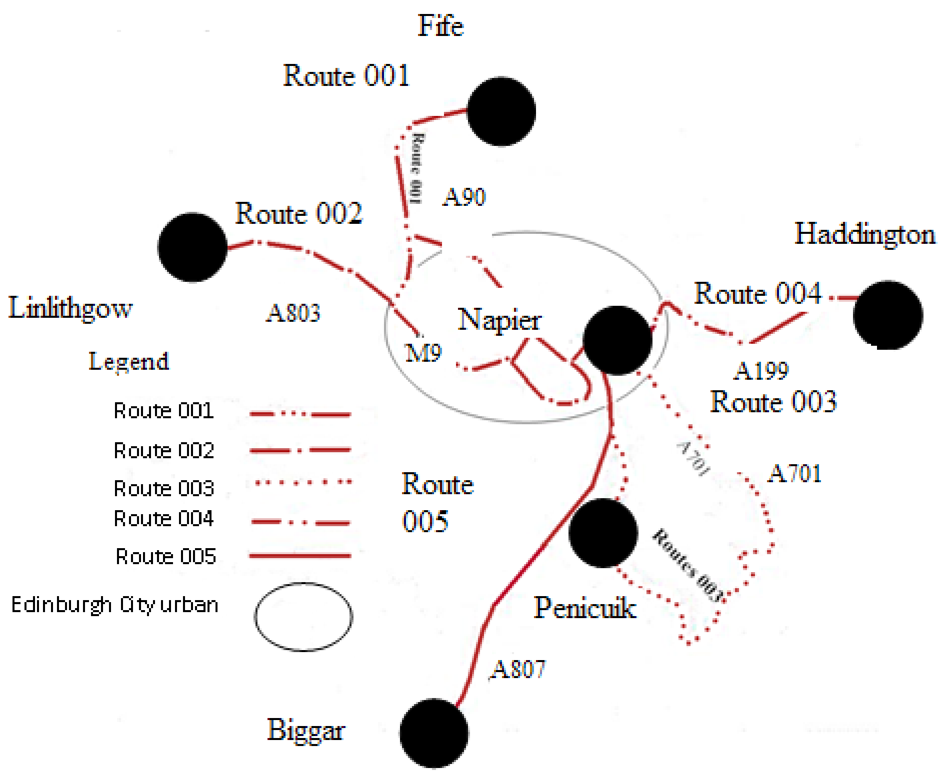


Figure 6.2 Schematic diagram of study area showing both the outside and inside residential centre and place of work (Napier University) in the city of Edinburgh

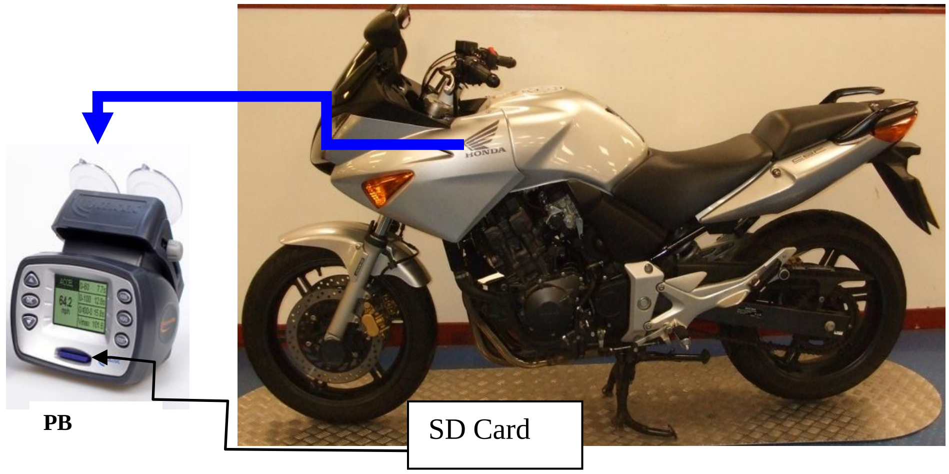


Figure 6.3 Test motorcycle with GPS-based Performance Box (PB)

6.3 Experimental equipment

In order to a develop data acquisition system for the driving cycle, the following equipment were used (Figure 6.3).

6.3.1 Test motorcycle

Each of five motorcycles was driven on one of the five selected routes. Four out of the five test motorcycles were Hondas. Characteristics of the motorcycles that have been used in the tests are shown in Table 6.2. All motorcycles were four-stroke petrol engines greater than 500 cc (they varied from 550 cc to 1000 cc, which was considered as reasonable representative of motorcycle engine sizes in Edinburgh). The average annual mileage travelled varies from 5000-10000 km. The oldest motorcycle was 18 years of age and the newest six years old.

Table 6.2 Characteristic of motorcycles used for test runs

Route	Model Year*	Manufacturer	Engine size (cc)	Age of the driver (yrs)	Weight (kg)	Average annual mileage (km)	Av. annual routine maintenance
001	1989	BMW	1000	50	250	10000	twice
002	1994	Honda	750	45	200	10000	twice
003	2001	Honda	550	55	176	10000	twice
004	1993	Honda	650	30	180	5000	twice
005	1998	Honda	794	44	200	10000	twice

**All the test run motorcycles have the pre-Euro or Euro standard*

6.3.2 *Performance Box (PB)*

The Performance Box is a high performance 10Hz Global Positioning System (GPS), which measures 10Hz logging of time, distance, speed, position, G-force, lap times and split times, as showed in Figure 6.3**.** The GPS receives signals from the satellites and gives global location of the moving vehicle in second-to-second intervals. During the testing, the Performance Box was kept in the carrying bag of the motorcyclist. The accuracy of the distance measurement is 0.05% (less than 50 cm per km), while the velocity measurement accuracy is 0.2 km h^{-1} (0.02%). The details of the specification and accuracy of measurement are given in Appendix 6.1**.** The PB is equipped with an MMC/SD flash memory card socket. This allows data to be logged on the MMC flash card, which can be analysed in detail using the PC software provided. A rechargeable battery powers the PB. The Performance Box can be connected to the USB port of a PC-compatible computer to download information stored on the memory card. The run data can be saved and viewed as .txt (Manual for Performance Box, 2007).

The Performance Box was installed either beneath the seat of the motorcycle or in the bag of the motorcyclist before start of their journey. A warm-up time of 10 minutes was also allowed to have less fluctuation in data logging. Onboard data was logged on Secure Digital card (SD), which is a flash (non-volatile) memory card of capacity 2GB manufactured by Kingston. This data was stored on a Pentium computer on a weekly basis. Distance, speed, acceleration, and time data were collected using a volunteer/owner on five different routes. Time-scale resolution of this data acquisition system was 0.1 seconds.

6.3.3 *Calibration of Performance Box*

Since the all-driving data was required to be collected by the PB the calibration of the PB was crucial before obtaining any data. The following steps were adopted for calibration of the PB.

- Identification of accurate mile posts with fixed distance (Figure 6.4)
- Clear roads during calibration process

- Clear weather for calibration test
- Clear instruction to driver to stop at marked line at mile post
- Authenticated distance between mile posts by regulatory authority

A clear chalk mark was made on the ground. The PB was stabilised for 10 minutes at the beginning of each run. Data was recorded by another professional staff, while the driver drove his motorcycle at the desired speed and stopped at the marked line. Three test runs were made along this mile route. Correct start time and elapse time was noted using a stopwatch (Table 6.3).

Table 6.3 Calibration of Performance Box

Date of calibration: 22/07/07,				Calibration Time: 07 PM		
Motorcycle: 1000 cc Honda,			Driver: Steve Middleton, Lecturer, SOBE			
Location: Glasgow M_2 junctions mile post						
Sr. no.	Test Run	Equipment Reading		Equipment Reading	Actual as per Traffic police data source (1/2 mile) in m	Difference (m)
Direction		Initial	Final	Final-Initial		
W-E	1	895.50	1703.20	807.70	804.67	3.03
E-W	2	1898.80	2705.90	807.10	804.67	2.43
W-E	3	3146.80	3952.80	806.00	804.67	1.33
						Average 2.261
						Percentage source of error = positive 0.28
						Claimed by PB for distance measurement 0.05%

Figure 6.4 Defined milepost of Edinburgh traffic police used for calibration of PB

The errors were calculated by finding the difference between the observed reading and the ground. The average error was found to be +0.2% (positive reading) greater than that claimed by the manufacturer (0.05%). Possible sources of error might be due to manual operation of the stopwatch and inaccuracy in GPS satellite positioning.

6.4 Data collection

6.4.1 Data collection method for developing real-world driving cycle for EMDC (urban and rural)

As discussed in the literature review different methods for surveys and data collection for developing driving cycles have been reported (Tzeng and Chen, 1998; Tong et al., 1999; Booth et al., 2001; Lin and Niemeire, 2002; Shafiepour and Kamalan, 2005). For the current research, the equipment was installed in tested motorcycles, which were driven by their owners' along their usual routes (i.e. commuting journeys from home to work) for a week. This was also considered as the most cost efficient way of collecting driving cycle data.

In the current circumstances of limited funding, volunteers were asked to fit the data acquisition system into their vehicle and drive their own usual journeys. Since the total number of motorcycles in fleet is small compared to other categories of vehicles, it was considered that the small sample obtained would be a good representation of the motorcycle population in Edinburgh. Both the onboard measurements of the driving cycle as well as motorcycle emission questionnaire were used and considered appropriate to achieve the objective of the research study. Design of the motorcycle emission research questionnaire provided useful information to assess the target factors affecting the driving cycle, which includes motorcycle engine size, engine type, and year, reason for buying motorcycle, fuel consumption, age, occupation, income, and details about routes travelled. These details were entered into a separate summary file of the database to preserve the attributes of the data.

As well as all the data collected from the driven motorcycles, the drivers were asked to fill in questionnaires to provide general information about motorcycle routes and general details of their age, purpose for driving etc. (A sample questionnaires is presented in Appendix 6.2). Volunteers normally performed their journeys during early morning (non-rush hour) and returned to their homes during the rush hours in the evenings. The measurements took place over the months of August, September, October and November of 2007. This period was not characterised as heavy winter (temperature was not less than 10° C). It was also based on the assumption that there would be no significant day-to-day variations but that there would be differences between weekdays and weekends, routes and drivers. Each day was covered by the morning peak (7.00 a.m. - 9.30 a.m.), afternoon peak (12.00 p.m. - 3.00 p.m.) and the evening peak (16.00 p.m. - 18.00 p.m.) periods, which take account of the daily variations. It was also expected that there would be differences in driving patterns due to the difference in activities at different periods.

6.4.2 Data logging, coding and classification

Before analysing, the database a systematic design of database was required for appropriate record keeping. Unique codes were generated which describe the property of routes, engine type, travel time and day, age of the driver and other characteristics as discussed below. Urban and rural roads were classified based on the speed limits (Highway Codes, 2007). The coding and classifications of the data were based on the major parameters involved in the driving cycle as shown in Table 6.4

The logged speed, acceleration, and decelerations were plotted against time data and inspected visually for any abnormal characteristics. Sometimes the GPS readings had some sudden drop down in a few test runs while logging data. Weather conditions, interferences of signals from high-rise walls, trees etc. may affect the continuity of the data capturing process. Even the data capturing was discontinuous at few points. The Performance Box software tool prompts repair of the file by clicking on the Tools menu and choosing the File Repair option (Manual for Performance Box, 2007).

Table 6.4 Coding and classification for generating input files for driving cycle development

Parameters	Sub-category	Code	Notes
Codes for volunteer bikes		001-999	
Week	Weekday	1	Binary parameter
	Weekends	2	
Dates	1-31	1	
Months	January-December	01-12	
Engine size (cc)	0-125	1	
	125-500	2	
	500-700	3	
	700-1000	4	
	>1000	5	
Routes	Urban	1	Speed limit <= 48.28032 km h^{-1}
	Rural	2	Speed limit up to 113 km h^{-1}
	Motorway	3	Speed limit up to 113 km h^{-1}
	Others	4	
Time of travel	AM	1	7-9.30 a.m peak
	PM	2	4-5.30 p.m peak
	AM off Peak	3	
	PM off Peak	4	
Age of driver	0-25	1	
	25-35	2	
	36-45	3	
	45-55	4	
Generated CODE for File	1101121111		

The data acquisition system has been explained in the previous section; it constitutes the database in which the vehicle usage, details of the engine sizes, road types, time of travel, operating conditions etc. were stored. The motorcycles are considered representative and a ‘typical part of traffic stream’ of Edinburgh, because all the drivers were mature, experienced, and regular commuters for a long period. In addition, those drivers were driving their usual journeys, so their driving behaviour was assumed representative. Speed-time trace data captured by the GPS describes the typical pattern of driving conditions taking into account the varieties of drivers. The testing duration varied from 07.00 - 09.30 (RHM), 16.00 - 18.00 (rush hours in the evening, RHE) and 12.00-15.00 (non-rush hours, NRH). Test runs were done five times for each route, a total number of 88 runs (44 urban and 44 rural trips) were finalised for analysis. Table 6.5 shows the breakdown of test runs over each of the urban and rural routes during different hours. The largest percentage of trips was made in the morning.

Table 6.5 Duration of the test runs of different periods

Test run	Test Run 001			Test Run 002			Test Run 003			Test Run 004			Test Run 005		
Road type	RHM	NRH	RHE	RHM	NRH	RHE	RHM	NRH	RHE	RHM	NRH	RHE	RHM	NRH	RHE
Urban	5	1	0	10	1	6	6	2	1	3	6	3	1	3	1
Rural	4	2	1	8	1	5	7	4	2				1	4	0
Total	9	3	1	18	2	11	13	6	3	3	6	3	2	7	1
Sub total	13			31			22			12			10		

Note: RHM= Rush Hour Morning; NRH = Non-Rush Hour; RHE = Rush Hour Evening

6.5 Assessment parameters for driving cycle development

Driving cycles can be investigated for each part of the journey. Assessment of the candidate/representative driving cycles often involves investigating a set of the cycle's comprehensive statistics, such as average speed, maximum and minimum acceleration, the positive kinetic energy, speed, and acceleration as root mean square (RMS) values, and the percentage idle time. Kent et al., (1978) characterized the driving data by the speed-acceleration relative frequency as well as by the overall parameters such as the average speed and root mean square acceleration. Gandhi et al., (1983) used idling time, acceleration time, cruising time, deceleration time, total time, trip length, average speed and cruising speed to characterise the driving cycle for Delhi.

Lyons et al., (1986) investigated the distance, mean speed, maximum speed, root mean square acceleration, mean positive acceleration, maximum and mean positive and negative acceleration, stops per km and positive kinetic energy to characterise the test runs and the corresponding synthetic run as compared with the original observations in Australia. The majority of the driving cycle assessment criteria were matched to within 10% of the target value.

Tzeng et al., (1998) used travel time, travel distance, average running speed (i.e. idle time is excluded), average acceleration of all acceleration phases (i.e. acceleration *a* is greater than 0.1 ms^{-2}), average deceleration of all phases (i.e. deceleration *d* is greater than 0.1 m^{-2}), mean length of driving periods (from start to idling), average number of acceleration and deceleration changes within one driving period, percentage of idling time (V less than 3 km h^{-1}, *a* less than or equal to 0.1 ms^{-2}, *d* less than or equal to 0.1ms^{-2}), percentage of acceleration time (*a* greater than 0.1 ms^{-2}), time percentage at constant speeds (*a* less than or equal to 0.1 ms^{-2}, *d* less than or equal to 0.1 ms^{-2}), & percentage of deceleration time as assessment parameters to characterise and compare the Taipei motorcycle driving cycle.

Tong et al., (1999) used nine assessment criteria: (a) average speed of the entire driving cycle (b) average running speed (c) average acceleration of all acceleration phases (d) average deceleration of all deceleration phases (e) mean length of driving period (f) time proportion of driving modes (idling, acceleration, cruise and deceleration) (g) average number of acceleration and deceleration changes within one driving period, (h) root mean square acceleration and (i) positive acceleration kinetic energy (PKE) to characterise the driving pattern in the urban areas of Hong Kong.

Andre, M. (2004) developed a driving cycle from a series of measurements of driving data in developing the ARTEMIS European driving cycle. The ARTEMIS European driving cycle considered the main driving characteristics (average speed, stop frequency and duration), their structures according to various driving conditions. The higher diversity of driving conditions was identified with the help of 12 clusters or classes derived by factor analysis of the speed profile.

Tsai et al., (2005) used 11 parameters in the assessment analysis to calibrate a driving cycle from motorcycles in Taiwan. In addition, factor analysis and cluster analysis have been used to identify trip conditions and driving cycle parameters (Andre 2004; Montegari and Naghizadeh, 2003). Booth et al., (2001) used five sets of different speeds and acceleration groups for the Edinburgh driving cycle. Hung et al., (2005, 2007) used nine and thirteen sets of relevant assessment parameters in the development of the car driving cycle for Hong Kong city.

This current study adopts a similar approach to that suggested by Hung et al., (2007) using twelve sets of assessment parameters in the investigation of EMDC as shown in Table 6.6 below. This approach has selected because it utilised a whole range of assessment parameters and latest published work in literature (in mixed traffic area).

Table 6.6 Assessment parameters for the driving cycle

Sr. No	Assessment parameters	Abbreviation	Units
1	Average deceleration of all deceleration phases	D	m sec^{-2}
2	Average acceleration of all acceleration phases	A	m sec^{-2}
3	Average speed of the entire driving cycle	V_1	km h^{-1}
4	Average running speed	V_2	km h^{-1}
5	Mean length of driving period	C	seconds
6	Time proportion of driving modes in idling (fraction of time spent at speed of 0-3 km h^{-1})	Pi	%
7	Time proportion of driving modes in acceleration (a >0.1 m sec^{-2})	Pa	%
8	Time proportion of driving modes in deceleration modes (d <0.1 m sec^{-2})	Pd	%
9	Time proportion of driving in cruising modes (a <=0.1 m sec^{-2}, d <=0.1 m sec^{-2})	Pc	%
10	Average number of acceleration and deceleration changes within one driving period	M	
11	Root mean square acceleration	RMS	m sec^{-2}
12	Positive kinetic energy (m sec^{-2})	PKE	m sec^{-2}

A random selection process was adopted for synthesising the collected driving data into candidate driving cycles. The best cycle was then selected based on the least value of the sum of the average absolute percentage error (AAPE) between the target statistics and derived EMDC urban and rural (Chapter 7).

6.6 Precautions for field and laboratory work during data collection

Fieldwork always has a number of potential challenges associated with it. It is important to identify the potential dangers before starting the field/experimental testing work so that any risk involved can be minimised. Potential main hazards that one can meet in the field and their potential solutions to avoid them have been summarised below.

Fieldwork related to the investigation of driving cycles for motorcycles takes place in a rural/urban outdoor environment. Drivers are constantly exposed to weather with limited opportunities for protection. Also driving data collection is often quite a dynamic activity, so sometimes drivers become aggressive/impatient to reach their desired destination to meet the time target for their desired purpose. This may affect the normal drive pattern, which may cause accidents. This can be compensated by wearing more protective clothes and jackets.

Secondly, while using the Performance Box, Palmtop device and the Gas Analyser, this equipment should be protected from potential threat of theft. They should be properly secured, placed, and removed carefully when used. The GPS signal can be obstructed, especially in urban areas (e.g. tall buildings and road works). In addition, if data logging is lost due to loose wire/power supply then it should be restored after fixing the wire. Dropdown data due to loss of satellite connection can be repaired by the PB software. However, proper care should be taken to avoid such conditions to minimise discontinuity in data logging of speed, acceleration etc.

The driving should be done with normal style without influencing the surrounding traffic and avoiding any danger to people. It is good practice for the fieldwork to be performed naturally and continuously although it might be unavoidable that normal driving behaviour might be affected[1].

A blank Risk Assessment form (RAF) can be obtained from Health and Safety department of Edinburgh Napier University and this should be filled in for each volunteer before taking part in the fieldwork. The form details the level of risk involved (whether it is moderate or high) and to what extent risk can be controlled. Risk assessment forms should be read and agreed by all team members before starting fieldwork. Volunteers must be properly insured as per DVLA legislation.

Road safety is a main concern during investigating the driving cycle of motorcycles. The Lothian & Borders Police Road Safety Unit has provided guidelines on ‘The Real Penalty for Speeding’. This guideline is in general to control speeding, which is frequent on rural roads in and around the Edinburgh region. In addition, there are various precautions associated with emission testing in the laboratory (for detailed instruction[2] .The derivation of the driving cycle using this assessment parameter on the data set is described in Chapter 7.

1 (Downloadable from http://www.rcahms.gov.uk/srp/srp_health_safety.doc. Accessed on 3rd May 2008)

2 (http://staff.napier.ac.uk/Services/has/guidance/fieldwork.htm).

6.7 Summary

The influence of the driving cycle on emissions is well documented. There are many methods available to derive the driving cycle. In this chapter, a practical approach for real-world data collection to develop motorcycle driving cycle in Edinburgh (urban and rural) has been described. The PB was calibrated and used to ensure quality of data and issues related to collection of driving data has been discussed. Five routes were selected and 44 trips were made along these routes to collect driving data using the PB. To derive the driving cycle 12 sets of assessment criteria were assessed and analyse. Data analysis for deriving motorcycle-driving cycle has been discussed in Chapter 7.

CHAPTER 7 MODELLING THE EDINBURGH MOTORCYCLE DRIVING CYCLES (EMDC)

7.1 Introduction

Modelling the Edinburgh motorcycles driving cycles requires synthesising the large amount of data collected from the field and questionnaires. The assessment criteria, pattern of use, location of driving, type of motorcycles significantly affect the representative driving cycle. The Edinburgh motorcycle cycle has been compared with derived Delhi motorcycle driving cycle (DMDC). This chapter discusses modelling methodology to develop Edinburgh motorcycle driving cycle, its characteristics in urban and rural areas.

7.2 Edinburgh motorcycle driving cycle

As discussed in Chapter 6, driving data was collected over five routes in Edinburgh city centre, urban and rural districts. There were four rural and five urban routes as shown in Table 7.1. Each testing period was comprised of a series of major kinematic sequences (i.e. speed vs. time curve) which were divided into a number of minor kinematics sequences (also called micro-trips). Each driver used the defined routes during weekdays. Forty-four urban and rural trips were composed of sub-micro trips caused by several stops at traffic signals or due to congestion. The PBs tracked these minor kinematic sequences for all the trips over the different routes. A large quantity of data was collected over 5 routes. Therefore a database was created with unique identifier for each trip detailing associated attributes. Data from the PB were assessed and analysed using Excel software to calculate the assessment parameters (data is collected every 0.1 seconds time intervals). Data on speed, acceleration/deceleration and distance were analysed for each of the urban and rural sections of the corridors utilising the speed time diagram for each run. The assessment parameters for the different driving modes (e.g. acceleration, deceleration, idling and cruising) were then set (see table 6.6) for each of the routes and for each of the test runs (The details of these routes and time of data collection is presented in Appendix 7.1). Thus a "driving cycle" was derived for each test run for every route. The EMDCs were derived by examining the statistical resemblance of 12 parameters as shown in Table 7.2. This determined a 'single representative driving cycle' for both urban and rural conditions. Part of these assessment parameters were also used in assessment of deriving driving cycles by several researchers (Tzeng 1999, Hung 1999, Tsai, 2003, Andre 2004, Kumar et al., 2008.)

The mean value, standard deviation (SD) and coefficient of variations (COV) of those assessment parameters were estimated for each of the 44 trips (Table 7.1) on the five test sections of urban and four on rural. The COV values were calculated to show the variations in the performance of the test runs in each of the urban and rural contexts. A further refining of the driving cycle was done by calculating the absolute sums of the relative error (Sj) then by selecting the driving cycle with minimum value of Sj. The relative error value for each of the parameters (Δ_k) (Eq. 7.1) is:

$$\Delta_k = \frac{(\bar{P} - P_{ijn}) * 100}{\bar{P}}$$

-------------Equation 7.1

Where k is an assessment parameter (k varies from 1 to 12) and Δ_k is the value of the relative error for parameter k, $\bar{P}$ is overall mean value of parameters. P_{ijn} is a parameter with a value of a route i (between 1 and 5) and route category j (1 for urban and 2 for rural category) and n (the number of test runs for each motorcycle). The absolute sum of the relative errors (Sj) was calculated for each (urban and rural) route type by summing up the individual relative error for a given route (Eq. 7.2):

$$S_j = \sum_{k=1}^{12} \Delta k$$

--------------- Equation 7.2

The minimum value of the sum of absolute error (%) Sj for urban and rural were found to be 1 and 1.61 respectively (See Table 7.2). Equations 7.1 & 7.2 were used to calculate the relative error values and the absolute sum of the relative errors and these are presented in Table 7.2.

The minimum value of the absolute relative error was observed in test run 003 and 004 for urban and rural sections. The driving cycle associated with the minimum cycle length for that test run has been selected as a representative candidate cycle of EMDC. The derived driving cycle was selected for the minimum cycle length for the test run 004 and 003 to represent the EMDC for each of the urban and rural sections respectively.

7.3 Characteristics of the EMDC

The mean values of the key parameters are presented in Table 7.1 with the derived EMDC for urban and rural sections shown in Figure 7.1 and. Figure 7.2. Speed is the most important criteria affecting traffic emission which is an important factor influencing the emissions of the vehicle (Tzeng, 1998). The average speeds of motorcycles in the urban and rural areas are 33.5 km h^{-1} and 49.73 km h^{-1}, but in some cases, drivers exceeded the speed limits. For example, the maximum average speeds for the urban and rural EMDC were 70 km h^{-1} and 120 km h^{-1}. Similarly, differences in the cycle length, speed, and vehicle operating time were observed. The average trip lengths for the urban and rural EMDC are 7.3 km and 9.1 km.

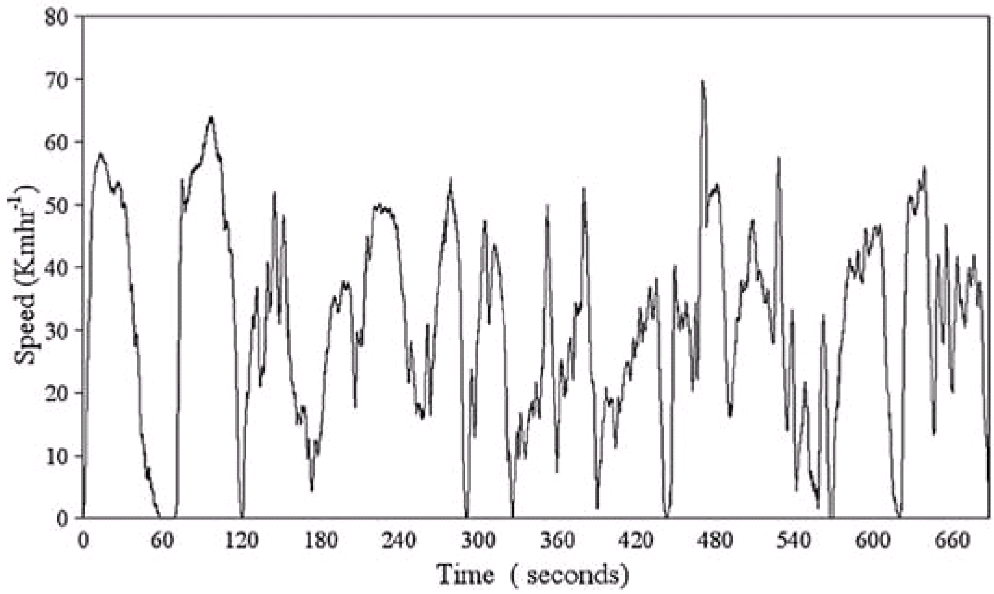


Figure 7.1 Representative driving cycle EMDC (urban)

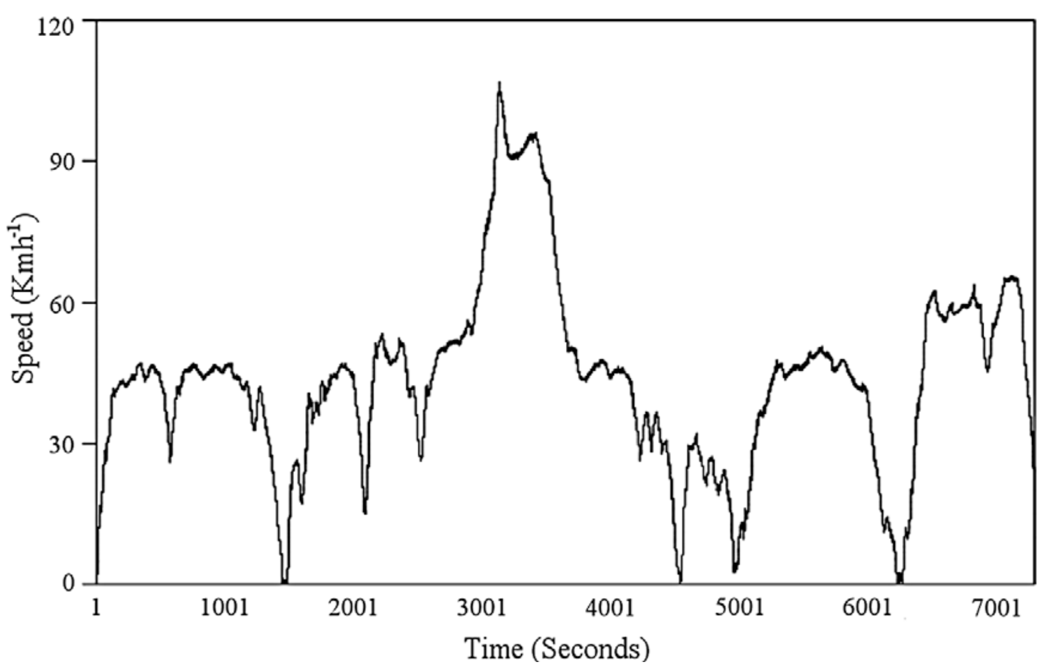


Figure 7.2 Representative driving cycle EMDC (rural)

Table 7.1 Value of the assessment parameters for different test run on five routes.

Route	Routes types	D ($m\ s^{-2}$)	A ($m\ s^{-2}$)	V_1 ($m\ s^{-2}$)	V_2 ($m\ s^{-2}$)	C (s)	Pi (%)	Pa (%)	Pd (%)	Pc (%)	M	RMS	PKE	Length (m)
001	Urban	0.89	0.97	39.32	41.18	710.33	0.32	42.98	48.32	8.44	1413.00	1.74	1.15	7783.51
	Rural	0.94	0.93	70.40	72.30	1179.64	0.14	43.07	47.45	9.38	1827.00	3.03	4.05	23233.49
002	Urban	0.98	1.00	32.00	34.50	622.68	1.35	44.01	47.95	6.94	1144.00	0.94	8.53	5375.41
	Rural	0.98	0.73	84.27	86.49	1210.76	0.69	44.02	44.13	11.53	2122.00	5.05	3.57	23718.08
003	Urban	1.27	1.12	38.85	40.98	488.82	2.33	44.99	47.14	5.63	1116.00	2.98	1.46	5611.49
	Rural	0.95	0.89	49.73	53.17	656.37	0.77	44.70	46.32	8.28	1349.00	2.09	2.05	9015.19
004	Urban	2.59	1.28	33.50	38.85	769.63	1.51	44.45	46.87	7.24	1251.00	7.83	2.81	7313.59
005	Urban	1.18	1.10	31.35	35.03	536.56	1.32	43.43	47.35	7.98	1028.00	3.71	0.69	3850.44
	Rural	0.81	0.76	70.17	73.06	1432.33	0.63	44.47	41.90	13.03	2732.00	3.02	3.51	28523.70
Average	Urban	1.38	1.09	35.00	38.11	625.60	1.37	43.97	47.53	7.25	1190.00	3.44	2.93	6.51
	Rural	0.74	0.66	54.91	57.00	895.82	0.45	35.25	35.96	8.44	1606.00	2.64	2.64	18.66
SD	Urban	0.69	0.12	3.81	3.19	116.80	0.72	0.80	0.60	1.08	148.00	2.68	3.23	1586.44
	Rural	0.07	0.10	14.23	13.71	328.79	0.28	0.72	2.46	2.13	578.00	1.25	0.86	8417.40
COV (%)	Urban	0.50	0.11	0.11	0.08	0.19	0.52	0.02	0.01	0.15	0.00	0.94	0.00	0.24
	Rural	0.08	0.12	0.21	0.19	0.29	0.51	0.02	0.05	0.20	0.00	0.37	0.00	0.45

Notes: Average values are the drawn across all the 44 test runs for urban and rural section

Where D: Average deceleration of all deceleration phases, A: Average acceleration of all acceleration phases, V_1: Average speed of the entire driving cycle, V_2: Average running speed, C: Mean length of driving period, Pi: Time proportion of driving modes in idling (fraction of time spent at speed of 0-3 km h^{-1}), Pa: Time proportion of driving modes in acceleration (a >0.1 m sec^{-2}), Pd: Time proportion of driving modes in deceleration modes (d <0.1 m sec^{-2}), Pc: Time proportion of driving in cruising modes (a <=0.1 m sec^{-2}, d <=0.1 m sec^{-2}), M: Average number of acceleration and deceleration changes within one driving period, RMS: Root mean square acceleration, and PKE: Positive kinetic energy (m sec^{-2}).

Table 7.2 The sums of absolute relative errors of the assessment parameters for urban and rural routes.

Route	D ($m\ s^{-2}$)	A ($m\ s^{-2}$)	V_1 ($km\ h^{-1}$)	V_2 ($km\ h^{-1}$)	C (s)	Pi (%)	Pa (%)	Pd (%)	Pc (%)	M	RMS	PKE	Sum of Absolute Error (%)
Rural routes													
R003	0.14	0.16	0.06	0.04	0.22	0.26	0.13	0.14	0.01	0.00	0.16	0.17	**1.61**
R005	0.06	0.08	0.13	0.13	0.23	0.18	0.13	0.09	0.22	0.00	0.08	0.15	1.72
R002	0.15	0.06	0.21	0.21	0.16	0.22	0.12	0.11	0.16	0.00	0.29	0.16	2.01
R001	0.13	0.18	0.13	0.13	0.15	1.34	0.11	0.15	0.06	0.00	0.08	0.21	2.74
Urban routes													
U004	0.29	0.09	0.03	0.01	0.11	0.06	0.01	0.01	0.00	0.00	0.34	0.03	**1.00**
U003	0.05	0.01	0.06	0.04	0.17	0.25	0.01	0.01	0.18	0.00	0.09	0.62	1.54
U002	0.25	0.06	0.06	0.06	0.00	0.01	0.00	0.01	0.03	0.00	1.63	0.40	2.53
U005	0.10	0.00	0.07	0.05	0.10	0.02	0.01	0.00	0.06	0.00	0.04	1.98	2.55
U001	0.34	0.08	0.07	0.05	0.07	2.00	0.01	0.01	0.09	0.00	0.60	0.95	4.35

Note: For both urban (U) and rural (R) routes, the error was also normalised by dividing with observed minimum value of sum of absolute error.

Where D: Average deceleration of all deceleration phases, A: Average acceleration of all acceleration phases, V_1: Average speed of the entire driving cycle, V_2: Average running speed, C: Mean length of driving period, Pi: Time proportion of driving modes in idling (fraction of time spent at speed of 0-3 km h^{-1}), Pa: Time proportion of driving modes in acceleration (a >0.1 m sec^{-2}), Pd: Time proportion of driving modes in deceleration modes (d <0.1 m sec^{-2}), Pc: Time proportion of driving in cruising modes (a <=0.1 m sec^{-2}, d <=0.1 m sec^{-2}), M: Average number of acceleration and deceleration changes within one driving period, RMS: Root mean square acceleration, and PKE: Positive kinetic energy (m sec^{-2}).

The rate of average deceleration–acceleration for urban EMDC was found to be higher than average deceleration–acceleration rate for rural EMDC, and was probably caused by the larger number of signals on urban roads. For urban EMDC, average running speed without idling (V_2) and average speed of entire driving cycle (V_1) were 38.85 and 33.55 km h^{-1} respectively. The values for urban EMDC were lower than those for rural EMDC. These differences were attributed to the higher speed limit (112 km h^{-1}) adopted by the Highways Agency in the UK for rural sections compared to urban ones (48 km h^{-1}/64 km h^{-1}). The mode of vehicle can be divided into idling accelerating, decelerating and constant cruising. For urban sections, percentage time spent in various operating modes such as idling (Pi), acceleration (Pa), and decelerations (Pd) are higher for urban sections than rural. Furthermore, time spent in cruise (Pc) was lower for urban than for rural sections for the probable reasons discussed above.

Overall the mean length of trips for the five test routes was 18.65 and 6.51 km for rural and urban travel respectively, but trip time on rural roads was approximately 60% of the journey time as compared to only 40% on urban roads; again, seemingly due to the small number of traffic signals on the rural roads.

During the course of this research, there has been an opportunity to validate the methodologies to derive driving cycles of motorcycles for a larger fleet and use of equipment and methods in another area. So to validate the methodologies, developed for EMDC, Delhi city (Delhi city has more than 65% of the traffic being two wheelers) motorcycle-driving cycle was derived out from real data which were collected in Delhi. Delhi motorcycles driving cycles (DMDC) were developed using the same methodologies and a characteristic comparison of EMDC to DMDC was carried out. Higher rates of acceleration and deceleration (two to three times) were observed for EMDC. The detail has been explained in Appendix 7.2.This illustrates the need to derive local driving cycles.

7.4 Summary

Driving cycles of motorcycles were investigated on different routes in Edinburgh city and its surrounding area using advanced GPS techniques. Large amounts of data on instantaneous speed under realistic road conditions were gathered. Based on these investigations, the driving cycles of motorcycles on different roads were analysed, and developed for both urban and rural roads, which are important for emission estimation. Derivation of driving cycles requires synthesis of a large amount of driving data. The EMDCs are constructed by synthesising the data of 44 trips across the north–south and east–west corridor of the city to represent the driving cycle of urban and rural conditions of the city. The developed EMDC for urban and rural areas were compared with the existing regulatory driving cycles and other cycles used for cars and motorcycles. There were significant differences observed across the different sets of parameters, such as time spent in different vehicle operating modes and rates of acceleration and deceleration. These findings are important for further efforts to control emissions in urban and rural driving conditions. Further discussions on the results are presented in Chapter 12.

CHAPTER 8 THE METHODOLOGY FOR EMISSION MEASUREMENTS

8.1 Introduction

Much research for car emissions has already been evaluated under real traffic conditions; however, application of onboard and laboratory methods to measure emissions from motorcycles is rare in local driving conditions in the UK (Chen, 2005, Kumar et al., 2009). In this chapter, emphasis is given to find the difference in emission factors of motorcycles for two different technologies and sizes under real-world driving and laboratory conditions. In the section, two types of emission measurements are discussed. Firstly, the on-board emission measurement system of motorcycles is described then the methodology for laboratory measurements using two engine sizes (1000 cc and 600 cc) is discussed. Emission measurements of CO, HC and NO_X emissions were undertaken during both experiments. The chassis dynamometer measurements were also undertaken for driving cycles like Edinburgh Motorcycle Driving Cycle (EMDC), WMTC and ECE driving cycle.

8.2 Experimental aspects of the on-board measurement method

(a) Test track

A series of tests were conducted over a 4.1 km test track along which Edinburgh City Council (ECC) monitors ambient air quality. The section of roads includes parts of Lothian Road, Princes Street and Queen Street. This track was chosen for two reasons: a) there was a case of exceeding the EU NO_X limits on this corridors and b) the same track was selected for real-world data collection of the driving cycle of Edinburgh for passenger cars (Booth, 2001). Figure 8.1 shows the test track and the AQMA location where the NO_X limits are exceeded.

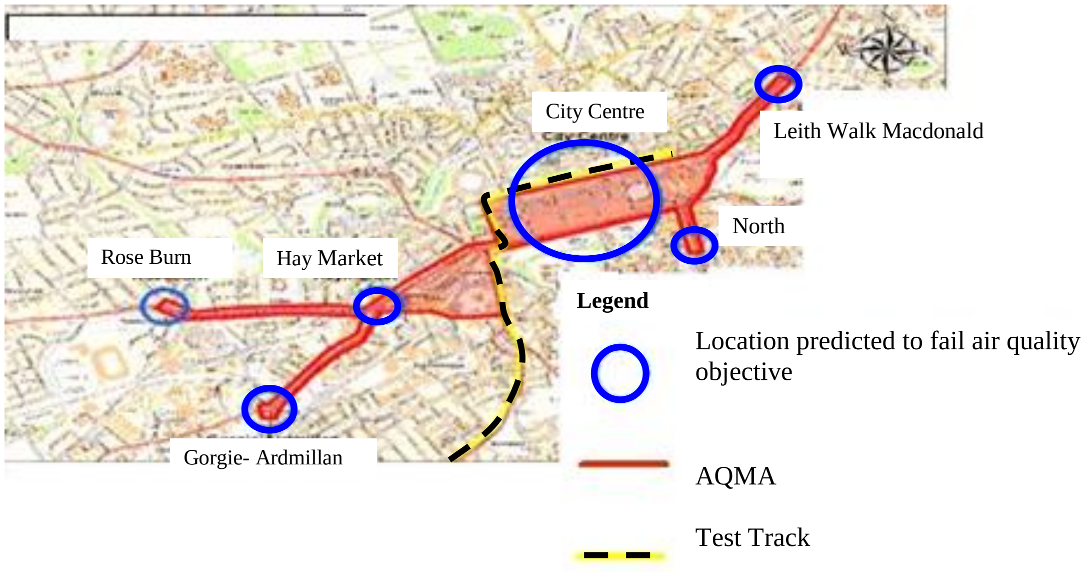


Figure 8.1 Test track for onboard emission measurement of motorcycle and AQMA in Edinburgh city

The test track covers nineteen traffic signals (one 5-arm, seven 4-arm and ten T-junctions). The speed limit is 48 km h^{-1} along the corridor and the total percentage of motorcycle traffic varies from 1-3% of the total fleet. The same test track is also used for developing the driving cycle for motorcycles using a micro-simulation approach (see Chapter 10 for details).

8.3 Equipment

For this work, an onboard emission measuring system has been designed. The block diagram of this system is shown in Figure 8.2. This includes the micro gas analyser, the GPS and Chassis dynamometer. The system consists of the sampling system of exhaust gases, the gas analysers, the software, vehicle speed, lambda sensor, the power supply and the data acquisition and automated data processing system. The details for each piece of equipment are given in following section.

8.3.1 ProBike Micro Gas Analyser (PMGA) and GPS engine Performance box

ProBike MicroGas (PMGA) is the ideal hand-held portable Exhaust Gas Analyser, which is easy to use with motorcycles. The PMGA is based on the latest micro-bench technology results into accurate measurement of carbon monoxide (CO); carbon dioxide (CO_2); hydrocarbons (HC); Oxygen (O_2); Lambda or Air/Fuel ratio, RPM and temperature. This is very lightweight and compact system (see Appendix 8.1 for description of the measurement principle). ProBike MicroGas allows flexibility for exhaust gas diagnosis and delivers far better performance.

PMGA has an optional printer, which uses infrared communication. It can also work without printer cable for printing. The comprehensive illuminated display provides straightforward clear information on a large, backlit dot matrix LCD on one screen (Probike, 2008).

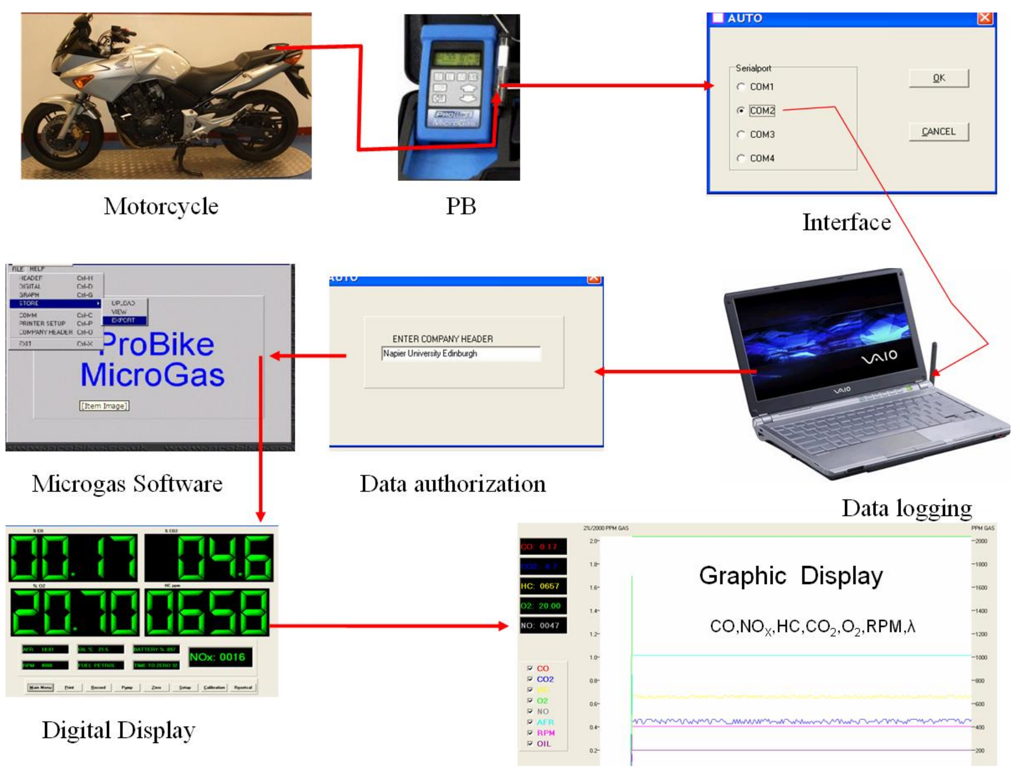


Figure 8.2 Block diagram of the on-board emission measurement system

8.3.2 *Test motorcycle*

Emission measurement tests involved two types of motorcycles: the popular Honda Hero model 600 cc (with Euro 2, direct injection petrol engine), and a 1000 cc BMW representing the old fleet (1990 but with different exhaust gas after-treatment technologies). The detailed descriptions of the test motorcycles are provided in Table 8.1

Table 8.1 Description of the test motorcycles

Description	Vehicle I	Vehicle II
Model Type	BMW	Hero Honda
Model Year	1989	2004
Emission Standard	Pre Euro	Euro 2
Engine Type	Fuel Injection	Carburettor
Displacement	1000 cc	600 cc
Stroke	4 Stroke	4 Stroke
Weight (kg)	250	167.8
Mileage (mile)	11000	23568

8.4 Data collection

In order to assess the on-road real emission factor, onboard emission measurements were made for five test runs as discussed below. ECC has installed several roadside air quality monitoring stations to monitor traffic emissions (see Figure 8.1) (ECC, 2006). Emissions data usually varies from test to test due to the variation in driver performance, external conditions, and engine and after-treatment temperature, apart from junction/location basis (Rijkeboer, 2005). Quality of emission data is important; therefore any unexpected large variations in travel time due to any incidents or events were discarded for analysis. Table 8.2 shows summary of the travel time for each test run, length and time of test. The driver drove the selected test routes, starting from Edinburgh Napier University to Queen Street via Lothian Road, South Charlotte Square and back (Figure 8.1). A subsection of routes from Shandwick Place to South Charlotte Square deviated from the original map due to implementation of the Edinburgh Tram Project across Princes Street. A typical sheet of raw data logged from the Microgas Analyser is presented in Table 8.3. This shows logged examples of emission data for HC (ppm), CO (%), CO_2 (%), O_2 (%), NO_X (ppm), oil, Lambda (λ) and time of logging. These data were imported to a Microsoft Excel environment using PMGA software for further analysis. Analysis of the data and results is presented in Chapter 9. The typical raw data sheet from the PB is presented in Table 8.4. This shows data of speed, distance, acceleration at every 10^{th} of a second. These data were obtained from different equipment.

Table 8.2 Scheduled and environmental conditions during onboard data collection

Date	Time (hr.minutes)	Engine Size (cc)	Total length of corridor (km)	Temperature (°C)	Weather Condition
25/02/2009	13.35	1000	7.8	10	Clear Sky
25/02/2009	14.145	1000	7.8	12	Cloudy
26/02/2009	13.22	1000	7.8	13	Clear
26/02/2009	13.47	1000	7.8	14	Clear
26/2/2009	14.13	1000	7.8	14	Clear
12/03/2009	14.06	600	7.8	10	Cloudy
12/3/2009	14.20	600	7.8	10	Cloudy
12/03/2009	14.45	600	7.8	12	Cloudy
13/03/2009	10.07	600	7.8	14	Clear
13/03/2009	10.37	600	7.8	15	Clear
13/03/2009	10.51	600	7.8	15	Clear

Table 8.3 Raw data sheet from gas analyser

HC (ppm)	CO (%)	CO_2 (%)	O_2 (%)	NO_X (ppm)	OIL	LAMBDA /AFR	TIME
6.00	0.24	1.30	19.54	9.00	38.40	10.27	10:56:55
6.00	0.23	1.20	19.73	8.00	39.00	10.81	10:56:57
6.00	0.23	1.20	19.82	7.00	43.50	10.85	10:56:59
5.00	0.22	1.10	19.93	6.00	37.80	12.03	10:57:01

Table 8.4 Raw data sheet from PB

Time (s)	Speed (km h^{-1})	Distance (m)	Acceleration /Deceleration (g)
0.00	0.00	0.97	-0.14
0.10	0.61	0.98	0.17
0.20	0.87	1.00	0.07
0.30	1.04	1.03	0.05
0.40	1.24	1.06	0.06

8.4.1 Data logging

Once the entire data acquisition system including the GPS system (Performance Box) was installed in motorcycle cycle, the driver drove the motorcycle to log the data. A proper fixation of PMGA, laptop and GPS is required to avoid damage/accident during the test run. The ambient temperature and time of travel was noted with the help of a thermometer and stopwatch. Finally, onboard data of emissions, speeds, and accelerations was stored on a laptop from the end of February 2009 to mid-March 2009. All data collection was undertaken in off-peak hours due to the limitation of availability of drivers. Details of engine size and time of on-board data logging are presented in Table 8.2. This shows that data were collected mostly during clear sky conditions. The ambient temperature varies from 10 $^{\circ}$C to 15 $^{\circ}$C. The data from the Performance Box was directly stored on an SD card, while data from the PMGA was stored via serial port to a laptop. The power supply of the laptop was adjusted to special closing modes, which allowed storing of the data in case of the lid closing during driving. The batteries of all the equipment were fully charged before downloading the data in driving mode. The test was done on two sets of motorcycle having different engine sizes (600 cc and 1000 cc). To obtain repeatability and similar operating conditions, the test procedures consists of driving each motorcycle along the same route (approximately 4.1 km one way) five times on different days with the same driver. This motorcycle driving cycle was made up of slow speed sections (because of the presence of traffic lights, roundabouts, pedestrian crossings etc.) and of high-speed sections in the Queens Street area of the city centre. The motorcycles were driven in the Edinburgh City centre area with normal driving styles.

8.4.2 *Synchronisation and processing of data*

Since there were two different data sets from two different instruments (all-raw data were stored in a database on daily basis), these data were processed to get the information in terms of detailed understanding of emissions. It is normal that there would be a time lag between the two different data loggers and data types: The data logging frequency of the Microgas analyser was 2 seconds (2 Hz), while the PB data used a frequency of 0.1 seconds (10 Hz) logging. The PB data was filtered to two seconds intervals using a small routine in the Excel file. Visual observations were also used to check continuity and synchronisation of data. Table 8.5 and Table 8.6 show the synchronised data from the PMGA and PB before and after processing (any errors in the data were discarded).

Table 8.5 Data logging from PMGA and PB before processing

PB Hertz (10)				PMGA Hertz (0.5)							
Time (1/10 Sec)	Speed (km h^{-1})	Distance (m)	Accel. (m s^{-2})	HC ppm	CO %	CO_2 %	O_2 %	NO_X ppm	RPM	OIL temp	Lambda /AFR
13:19:36:0	0.00	0.00	-0.83	5	0.04	0	20.68	0	0	14.1	-0.001
13:19:36:1	3.03	0.04	0.86	-	-	-	-	-	-	-	-
13:19:36:2	2.94	0.12	-0.03	-	-	-	-	-	-	-	-
13:19:36:3	2.94	0.21	0.00	-	-	-	-	-	-	-	-
13:19:36:4	2.99	0.29	0.01	-	-	-	-	-	-	-	-
13:19:36:5	3.03	0.37	0.01	-	-	-	-	-	-	-	-
13:19:36:6	3.09	0.46	0.02	-	-	-	-	-	-	-	-
13:19:36:7	3.16	0.54	0.02	-	-	-	-	-	-	-	-
13:19:36:8	3.22	0.63	0.02	-	-	-	-	-	-	-	-
13:19:36:9	3.33	0.72	0.03	-	-	-	-	-	-	-	-
13:19:37:0	3.36	0.82	0.01	-	-	-	-	-	-	-	-
13:19:37:1	3.61	0.91	0.07	-	-	-	-	-	-	-	-
13:19:37:2	3.88	1.02	0.08	-	-	-	-	-	-	-	-
13:19:37:3	4.11	1.13	0.07	-	-	-	-	-	-	-	-
13:19:37:4	4.42	1.25	0.09	-	-	-	-	-	-	-	-
13:19:37:5	4.74	1.37	0.09	-	-	-	-	-	-	-	-
13:19:37:6	4.98	1.51	0.07	-	-	-	-	-	-	-	-
13:19:37:7	5.19	1.65	0.06	-	-	-	-	-	-	-	-
13:19:37:8	5.44	1.80	0.07	-	-	-	-	-	-	-	-
13:19:37:9	5.64	1.95	0.06	-	-	-	-	-	-	-	-
13:19:38:0	5.79	2.11	0.04	6	0.82	1	14.15	28	0	14.5	6.468
13:19:38:1	6.02	2.27	0.07	-	-	-	-	-	-	-	-
13:19:38:2	6.26	2.45	0.07	-	-	-	-	-	-	-	-
13:19:38:3	6.47	2.62	0.06	-	-	-	-	-	-	-	-
13:19:38:4	6.81	2.81	0.10	-	-	-	-	-	-	-	-
13:19:38:5	7.06	3.00	0.07	-	-	-	-	-	-	-	-
13:19:38:6	8.61	3.22	0.44	-	-	-	-	-	-	-	-
13:19:38:7	8.36	3.45	-0.07	-	-	-	-	-	-	-	-
13:19:38:8	8.18	3.68	-0.05	-	-	-	-	-	-	-	-
13:19:38:9	8.23	3.91	0.01	-	-	-	-	-	-	-	-
13:19:39:0	8.19	4.14	-0.01	-	-	-	-	-	-	-	-
13:19:39:1	8.17	4.37	-0.01	-	-	-	-	-	-	-	-
13:19:39:2	8.27	4.59	0.03	-	-	-	-	-	-	-	-
13:19:39:3	8.19	4.82	-0.02	-	-	-	-	-	-	-	-
13:19:39:4	8.24	5.05	0.01	-	-	-	-	-	-	-	-
13:19:39:5	8.27	5.28	0.01	-	-	-	-	-	-	-	-
13:19:39:6	8.30	5.51	0.01	-	-	-	-	-	-	-	-
13:19:39:7	8.38	5.74	0.02	-	-	-	-	-	-	-	-
13:19:39:8	8.46	5.98	0.02	-	-	-	-	-	-	-	-
13:19:39:9	8.44	6.21	-0.01	-	-	-	-	-	-	-	-
13:19:40:0	8.35	6.44	-0.03	6	2.16	2.3	9.79	38	0	17	2.323

Table 8.6 Data from PMGA and PB after processing

PB				PMGA							
Time (2 sec)	Speed (km h^{-1})	Distance (m)	Accel. (m s^{-2})	HC ppm	CO (%)	CO_2 (%)	O_2 (%)	NO ppm	RPM	OIL temp	Lambda /AFR
13:19:36	0.00	0.00	-0.83	5.00	0.04	0.00	20.68	0.00	0.00	14.10	0.00
13:19:38	5.79	2.11	0.04	6.00	0.82	1.00	14.15	28.00	0.00	14.50	6.47
13:19:40	8.35	6.44	-0.03	6.00	2.16	2.30	9.79	38.00	0.00	17.00	2.32
13:19:42	8.30	11.14	0.00	472.00	4.11	5.30	6.33	39.00	0.00	17.80	1.23
13:19:44	7.74	15.64	0.02	472.00	4.86	5.20	4.25	43.00	0.00	13.20	1.03
13:19:46	2.18	18.79	-0.07	472.00	5.32	6.70	2.70	60.00	0.00	27.20	0.93
13:19:48	1.08	19.52	0.06	505.00	5.38	9.20	2.96	61.00	0.00	30.40	0.95

8.4.3 Estimation of fuel consumption from onboard measurement

There was no instantaneous onboard fuel consumption measurement in any of the vehicles. Fuel sensors could have been installed in the motorcycles to measure the instantaneous fuel consumption, but installation of fuel meters requires the modification of the engine. And as per legislative regulation in UK, drivers are not allowed to make any changes to or tamper with the engine, so this was not possible. Instead, crude estimates for fuel consumption were used: the petrol tank was filled to neck level before the start of each test run. After 2-3 consecutive runs, the tank was topped up again to neck level to measure the volume of fuel consumed. The difference of weight of fuel before and after the test was used as fuel consumed over test run. This value was divided by total travel time to give fuel consumption for each test run. Equation 8.2 below shows the calculation method used:

Fuel consumption (gm/sec)

$$= \frac{W(_P +_C)_b - W(_{P+C})_a}{n * t}$$ **------------------------------Equation 8.1**

Where W = weight (gm), P= petrol, C = can, B = before, a = after test run; n = total number of test runs; t = travel time (sec).

This method is discussed further in the limitations section of Chapter 2. Therefore, the emission measurement using fuel consumption might be subject to error, and overall emission results could be subjective and have errors; however, it was attempted to distribute these errors every second and instantaneous measurement of emissions provide more realistic estimates than other types of emission testing in spite of these errors. In addition, fuel consumption can be very accurately determined using the carbon balance method, from the mass emissions of CO, CO_2 and THC. The PMGA also measures the lambda factors, which allow calculating the most reasonable value of fuel consumption. In this case, exhaust gas was diluted with ambient air due to measurement in an open environment; therefore, the carbon balance method was not appropriate to estimate. However, the equation used by Tong et al., (2000) was utilised to measure emission with crude estimates of fuel consumption.

8.4.4 Emission estimates from on road emission measurement on AQMA area

Equations 8.2 - 8.4 have been used in this research to measure instantaneous emission rates (gm/sec). These have been as adopted from Tong et al., (2000):

$$CO_{\mathbf{g/sec}} = \frac{(m_{air} + m_{fuel})}{Mexhaust} * M_{CO\%} * CO_{\%} * 10^{-2}$$ ----------------------**Equation 8.2**

$$HC_{\mathbf{g/sec}} = \frac{(m_{air} + m_{fuel})}{Mexhaust} * M_{HC\%} * HC_{ppm} * 10^{-6}$$ -----------------------**Equation 8.3**

$$NOX_{\mathbf{g/sec}} = \frac{(m_{air} + m_{fuel})}{Mexhaust} * M_{Nox\%} * NOx_{ppm} * 10^{-6}$$ ------------------------**Equation 8.4**

Where,

M_{CO} is the molecular weight of CO = 28.01

M_{HC} is the molecular weight of the exhaust HCs (based on 1C atom),

$$[(12.011 + 1.088y + 15.99z);]$$

Where *y* is the HC atomic ratio in the fuel (assuming the exhaust HC=fuel); *z* is the O/C ratio in the fuel (assuming the exhaust HC= fuel);

M_{NOx} is the molecular weight of NO_X

$$[(14.007 + 15.99) + (14.0078 + 15.99 * 2) * 0.1] / 1.1 = 31.46$$

$M_{exhaust}$ is the molecular weight of the exhaust

$$(13.88 * HC_{ppm} * 10^{-6}) + \left(28.01 * CO\% * 10^{-2}\right) + \left(44.01 * CO_2\% * 10^{-2}\right) + (46.01 * NO_{x_{ppm}} * 10^{-6}) +$$
$$(32.00 * O_2\% * 10^{-2}) + (2.016 * H_2\% * 10^{-2}) + (32.00 * O_2\% * 10^{-2}) + (2.016 * H_2\% * 10^{-2})$$
$$+ 18.01 * (1-k) + [100 - \frac{HC_{ppm}}{10^{-4}} - CO\% - CO2\% - \frac{NO_x ppm}{10^{-4}} - O_2\% - (H_2\%) -$$
$$100 * (1-k) * \left[100 - \frac{HC_{ppm}}{10^4} - CO\% - CO_2\% - \frac{NO_x ppm}{10^4} - O_2\% - (H_2\%) - 100 * (1-k)\right] * \frac{28.01}{100}];$$
$$k \ \ is \left[1 + 0.005 * (CO\% + CO_2\%) * y - 0.01 * H_2\%\right]^{-1}$$
$$and$$
$$H_2\% \ = \frac{0.5 * y * CO\% * (CO\% + CO_2\%)}{(CO\% + 3 * CO_2\%)}$$

The instantaneous emission rates of CO, HC and NO_X for both vehicles were calculated by the standard method described by the above equation. Emissions and fuel consumptions are usually calculated as average values over several test runs and then parameterized in terms of the corresponding average speeds and accelerations. In fact, on-road driving is random combinations of the four standard driving modes; acceleration, cruising, deceleration and idling. It is of great interest to practitioners to characterise emissions and fuel consumptions behaviour during different driving modes.

Vehicular emission can be expressed in terms of grams of pollutants emitted per unit time, per unit distance travelled, or per unit fuel consumed. Accordingly, three terms are defined to describe vehicular emissions and fuel consumption: average vehicular emissions and fuel consumption over a trip were expressed in distance based (g/km) unit; average emission was calculated by Equations 8.5 - 8.6. All of the factors and indices were calculated over the whole data sample for both vehicles, and results were compared with Euro emission norms, which are used by the Air Quality Authority in the UK. The details of the results and data are discussed in Chapter 9.

Average emission factor [g/km] = $3600 * \frac{\sum e(g/\sec)}{\sum V[km/hr]}$ ----------------------**Equation 8.5**

Average fuel consumption factor [g/km] = $3600 * \frac{\sum f(g/\sec)}{\sum V[km/hr]}$ -----------**Equation 8.6**

Where *e* is the instantaneous emission rates of the pollutant gas, *f* is the instantaneous fuel consumption rates (gm/sec) and *V* is the instantaneous vehicle speed (km h^{-1}).

Data obtained from the PB included acceleration data in term of gravity (g); this was converted into m/sec^2 by multiplying factor of 9.81 m/sec^2. The corresponding emission and fuel consumption data were then classified according to various driving modes. The four standard driving modes were defined as follows in

Table 8.7:

Table 8.7 Driving modes definition

Driving modes	Criteria 1	Criteria 2	Interval	Acceleration Type
Idling	0-3 km h^{-1}	+ acceleration	0.1 sec	+
Acceleration	> 0.1m /sec^2	+ acceleration	0.1 sec	+
Cruising	> 0.1m /sec^2	>3 km h^{-1}	0.1 sec	+
Deceleration	< 0.1m /sec^2	- acceleration	0.1 sec	-

The value of 0.1 m/sec^2 was used by different researchers in defining driving modes (Cernushi, 1995; Tong, 1999; Hung et al., 2007; Kumar et al., 2008) and used in developing the EMDC as discussed in Chapter 6. The average values of instantaneous emission and fuel consumptions rate (g/sec) were calculated for each vehicle. Data obtained from each test vehicle were grouped together. Thus, there were two sets of instantaneous speed and instantaneous acceleration. One set of emission data was for seven runs of the 1000 cc engine type and another set for five tests runs of the 600 cc engine type in off-peak times. To see the emission variation, emission testing was also done using a chassis dynamometer, which is discussed below.

8.5 Dynamometer testing procedures

One of the main aims of this research was to compare and evaluate the emission measured from driving a motorcycle on the selected corridor and emission obtained under laboratory conditions. It was possible during the course of the research to obtain emission measurements from a laboratory (Technical University Graz, TU Graz) on other driving cycles. Two similar types of motorcycle (as used in the onboard emission testing) were tested in the Laboratory of the TU Graz at the Institute for Internal Combustion Engines and Thermodynamics, Austria. Those were tested on a chassis dynamometer for three types of driving cycle according to (a) Emission test Directive 2003/77/EC of 18.08.06, (b) WMTC and (c) EMDC urban and rural. The typical schematic diagram of chassis dynamometer and testing procedure are presented in Figures 8.3. and 8.4. Testing was carried out from January to April 2009. Room test temperature and humidity were maintained at 22°C and 28% respectively. Throughout the testing process, a variable-speed cooling blower was positioned in front of the motorcycle to direct the cooling air to the motorcycle in a manner, which simulates actual operating conditions. The blower was placed such that within the operating range of 10 - 50 km h^{-1} the linear velocity of the air at the blower outlet was within ±5 km h^{-1} of the corresponding roller speed. The test fuel was selected in accordance with manufacturer requirement. The chassis dynamometer comprised the test motorcycle, dynamometer, CVS system, blower, sampling bag and analyser (Appendix 8.3).

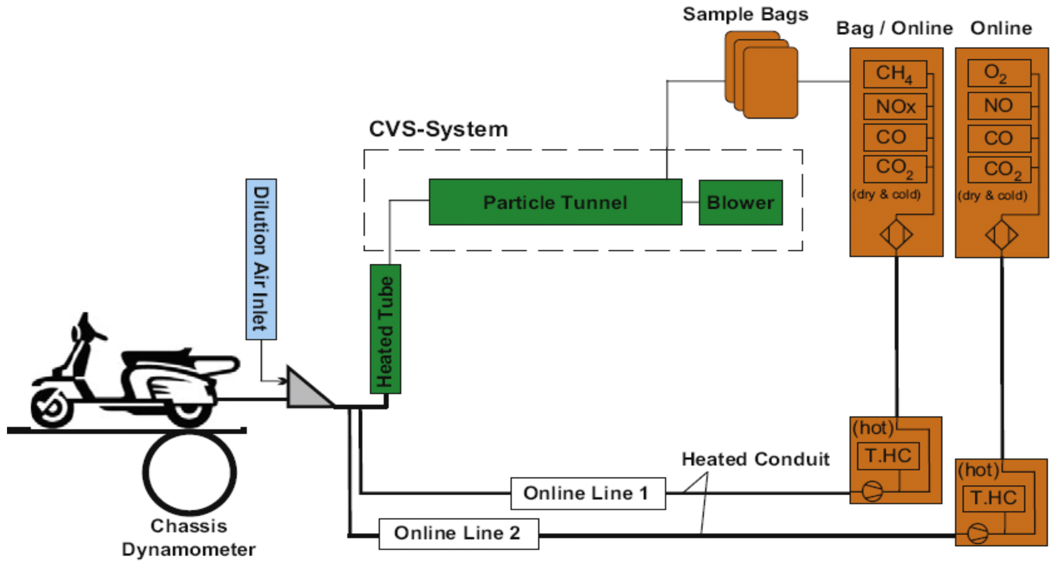


Figure 8.3 Schematic diagram of chassis dynamometer test setup

Figure 8.4 Laboratory testing on chassis dynamometer test setup with online data monitoring and conditioned system with CVS

The description of the test vehicle is presented in Table 8.8. Although test motorcycles were chosen to represent the similar, engine size and model year used for on- board measurements in Edinburgh City centre, there were some differences in the characteristics of the vehicles and the ones used in Edinburgh. Fourteen tests were carried out under different driving conditions using the two sets of motorcycles. The vehicles were subjected to the standard reference conditions mentioned in the BS code (2007) (Chapter 4). A constant volume sampler was used to collect exhaust gasses at motorcycle exhaust outlets providing that it satisfied the backpressure condition of ±1.226 kpa. The typical schematic diagram for gas sampling is shown in Appendix 8.2, and the CVS has been labelled. The adopted driving cycle and testing programme is presented in Table 8.9 ; the result obtained from this testing is presented in Chapter 9.

Table 8.8 Description of test vehicles on chassis dynamometer

Vehicle Manufacturer	Vehicle type	Displacement (cm^3)	Mileage (km)	Chassis No.	Reference weight (kg)	Tyre pressure (bar)
Honda	CBR600F	599 (~600)	11565	JH2PC35G9M302631	280	3
Kawasaki	Z1000E	1015 (~1000)	50000	KZT00E-002492	360	3

Table 8.9 Description of driving cycles and their schedules

Sr. No.	Driving Cycle	Model	Engine size	Temp. (°C)	Humidity (%)	Distance (km)	Test date	Air Pressure (Pa)
ECE								
1	Euro driving cycle	Kawasaki	1015	22.5	28	12.95	23.03.2009	962.4
2	Euro driving cycle	Hero Honda	599	22.4	31	12.98	02.02.2009	979.1
EMDC								
3	EMDC urban	Hero Honda	599	22.1	28	5.86	03.04.2009	980.5
4	EMDC Rural	Hero Honda	599	22.1	28	8.87	03.04.2009	980.5
5	EMDC cumulated	Hero Honda	599	22.1	28	14.73	03.04.2009	980.5
6	EMDC urban	Hero Honda	1015	22.5	28	5.84	24.03.2009	980.5
7	EMDC Rural	Hero Honda	1015	22.5	28	8.82	24.03.2009	980.5
8	EMDC cumulated	Hero Honda	1015	22.5	28	14.66	24.03.2009	980.5
WMTC								
9	WMTC part 1	Kawasaki	1015	22	28	12.95	02.04.2009	963
10	WMTC part 2	Kawasaki	1015	22	28	12.95	02.04.2009	963
11	WMTC part 3	Kawasaki	1015	22	28	12.95	02.04.2009	963
12	WMTC part 1	Hero Honda	599	22.5	28	12.95	02.04.2009	979.8
13	WMTC part 2	Hero Honda	599	22.5	28	12.95	02.04.2009	979.8
14	WMTC part 3	Hero Honda	599	22.5	28	12.95	02.04.2009	979.8

8.6 Precaution for laboratory testing

The following precautions which are mentioned in the BS standards should be adhered while laboratory measurement. BS code states, the following guidelines for laboratory conditions that the following should be maintained, while testing apart from engine, driving behaviour and fuel type:

Total barometric pressure P_o 101325

Air Temperature T_0	293.15 K (20^0C)
Relative humidity, H_0	65%
Air volumetric mass ρ_0	1205 kg/m^3
Relative air density, d_o	0.9319

Driving behaviour: Different driver has different type of driving style even they have strict driving cycle. Possibly one driver should carry out the entire test.

Number of runs: To get more generalised result, more number of runs should be carried out by using more personnel. In our study we have just done three test for three type of driving cycle due limitation of budget and time.

Engine Size: Emission testing should be carried out on almost all type motorcycle in the fleet to get wide range of emission behaviour, however in our study emission testing is done on most representative engine size >500 cc and >1000 cc.

Engine condition before testing: Proper soak time should be allowed to measure the emission and if engine are hot then cooling fan should be placed in front of engine to maintain the engine temperature, which simulates actual operating conditions. The blower was placed such that within the operating range of 10 km to 50 km h^{-1}, the linear velocity of the air at the blower outlet was within ±5 km h^{-1} of the corresponding roller speed.

Fuel: The test fuel should be selected in accordance with manufacturer requirement.

8.7 Summary

In this chapter, emission measurement methodologies for onboard measurement and laboratory measurement using a chassis dynamometer have been discussed. The onboard emission measurement was performed on the AQMA corridor in Edinburgh using motorcycles with two different engine sizes. An appropriate data acquisition system has been designed in this research to measure on-board emissions, speed and acceleration data simultaneously with the help of the latest available equipment and software. In addition, emission measurement methodology using chassis dynamometer is discussed, which took place during standard laboratory measurements at the University of Graz. Three sets of driving cycles were listed to obtain the emission patterns of motorcycles using two different engine sizes, which were similar to the motorcycles used along the AQMA in Edinburgh with contrast in their mileages driven. The detailed data analysis is discussed in Chapter 9.

CHAPTER 9 ANALYSIS OF ON BOARD AND LABORATORY EMISSION MEASUREMENTS

9.1 Introduction

This chapter explains the data analysis of onboard and laboratory emission measurement using two sets of motorcycles of 1000 cc and 600 cc engine size. Characteristics of instantaneous emissions with time, speed, acceleration have been investigated. Average emission factors for CO, HC, and NO_X along the corridor have been compared with emission factors obtained from laboratory measurements. Also, modelling of modal emission factors, which are mostly suited in evaluation of ramp metering, signal coordination and widely used in ITS has been explored by classifying the vehicle operating data into acceleration, deceleration, cruise and idling (Kumar, 2009).

To meet these objectives repeated numbers of onboard emission measurements were made along AQMA. Overall, the characteristics of the seven sets of data for 1000 cc and five sets of data of 600 cc motorcycles are presented in Table 9.1. It can be seen that the average speed is 23.603 km h^{-1} , which is higher than those of the car driving cycle (Booth et al., 2001). Booth et al. (2001) reported speeds for EDC of 20 km h^{-1}. In our measurements, ambient temperature varied from 10-15 $^{\circ}$C. The distance travelled ranged between 7680.52 metres to 8180 metres. This difference of travel distance was attributed to diversion in following the exact path during the course of the test run: the driver made minor deviations in routes due to route changes announced by ECC for execution of the current tram project across the city centre. Details of the extracted data have been presented in Appendix 9.1. It should be noted that due to unavailability of satellites in some areas, the GPS does not provide accurate data in some parts of corridor, so some data from test sections were discarded.

Table 9.1 Characteristics of the test runs

Sr. no	Time of test run (am/pm)	Engine size (cc)	Distance travelled (m)	Duration (sec)	Average speed (km h^{-1})	Ambient temperature ($^{\circ 0}C$)
1	PM	1000	7680.52	1110.00	24.91	10.00
2	PM	1000	7830.91	1156.00	24.39	12.00
3	PM	1000	8033.00	1408.00	20.54	13.00
4	PM	1000	7988.95	1358.00	21.18	14.00
5	PM	1000	7966.22	1282.00	22.37	14.00
6	PM	1000	7969.52	1166.00	24.61	14.00
7	AM	1000	8056.00	1062.00	27.31	13.00
8	PM	600	8119.47	1374.00	21.27	10.00
9	PM	600	7976.56	1088.00	26.39	12.00
10	AM	600	8013.08	1298.00	22.52	14.00
11	AM	600	8180.35	1358.00	21.69	15.00
12	AM	600	8036.00	1110.00	26.06	15.00

9.2 Data quality assurance and control (QA/QC)

It is critical for data analysis that we have confidence in the second-by-second mass emission rates. However, during very fast transient events, a slight time delay (less than one second) between the two measurements can cause errors in the modal emission rate. Most of these events occur during rapid deceleration, when there is a rapid decrease in dilution ratio that causes a slower response of the emission to the analyser. This results in a higher emission rate for a period of one to two seconds.

One way to continually validate our results and check for this problem is to aggregate the second-by-second mass emission rates in grams per second. Therefore, obtained results from the gas analyser were aggregated to get the total mass emissions in grams over the entire AQMA test section. The emission factors in grams/km for each test and each cycle can be obtained by dividing the total emission in grams by the distance travelled along the routes of driving (Equation 8.6 to 8.8, Chapter 8).

Another check of the collected data was done by using the visual check of the second-by-second emission profiles for each pollutant after each test run. The time alignment between emissions of each pollutant and the driving trace obtained from the Performance

Box, as well as the overall emission profile, was specifically inspected. For example, the engine-out CO_2 emissions profile should be similar to that of the engine-out HC and NO_X emissions. It was also verified to make sure that emission rates at a given second were not unreasonably high or low. If this was found during testing then the test run was repeated.

Carbon balance check is another method of validation of the data. This is done by calculating the amount of carbon in the pre- and post-catalyst lines. These two numbers should be approximately equal. Large discrepancies in pre- and post-catalyst lines may indicate a leak in the vehicle test system. In order to test a vehicle, it is necessary to drill and weld a tap for a sample probe. Such a leak could be occurring on the exhaust pipe between the two sampling taps or from one of the taps itself. A leak would cause a portion of ambient air to be drawn in with the sample diluting it, which would result in lower concentrations and, subsequently, in lower mass emission values. By comparing the pre- and post-catalyst carbon numbers, we can calculate a second-by-second adjustment factor, which can be applied to carbon imbalance data in order to correct it.

For our study, no leak was found in the catalyst line of these two motorcycles, as both motorcycles have an MOT certification. The MOT scheme is primarily a road safety measure designed to ensure as far as possible that all cars, motorcycles and light goods vehicles more than 3 years old are properly maintained and at least are examined at an authorised MOT test station to make sure that they comply with certain important requirements of the law. However, emission measurement was done in dilution of exhaust with ambient air because there was no control of the emission measurement in the field as compared to laboratory due to restriction of funds and legislation binding. In the measurement of emissions, the exhaust pipe was open and gas was analysed based on intensity of exhaust coming out of the engine. These conditions confirmed that the sample collection was not done in a controlled environment. For the laboratory, standardised and control sampling process can be defined as per BS standards, but there is no specific or standard on how to measure emissions onboard for motorcycle in UK conditions.

9.3 Instantaneous on board emission along the AQMA

Instantaneous emission aims to describe the precise emission of vehicle operating in different modes during a series of short time steps (it may be 1-second intervals or less). It has following advantages:

- Emission can be calculated for any vehicle operating profile. Thus new emission factors can be generated without the need for further testing.
- Instantaneous emission can take the dynamics of any driving pattern. Therefore, it can be used to explain the variability in emissions associated with given average speeds.
- Instantaneous emission allows spatial observation. This could lead to improvement in prediction of air pollution along the corridor. Air quality models typically assume that emissions are evenly distributed along the road section, it is therefore likely that such models will under-predict emissions and resulting ambient concentrations at some locations, such as near intersections.

A description of the emissive behaviour of each vehicle is required to improve the accuracy of emission assessments. The instantaneous emission records exhibit periods of high emission levels that are long in regard to kinematics patterns. Table 9.1 and Table 9.2 shows onboard real-world emissions of HC for a 1000 cc engine, illustrating the example of instantaneous emission measured along the test corridor. The peak emission traces for the on-board tests showed that emission rates are higher for the 1000 cc motorcycles than 600 cc; however, in the case of HC, it was lower than 600 cc separately (Figure 9.1).

Thus, it makes sense to investigate the emission patterns of the 1000 cc and 600 cc engine sizes separately. The emissions were calculated on both directions along 8.2 km of the AQMA test route in average durations of 20 minutes. This includes up and down direction (both direction) by motorcycles on the test corridors of total distance of 8.2 km. Fuel consumptions were calculated as discussed in Section 8.4.3, while total emissions were extracted from the ProBike MicroGas Analyser and expressed as ppm for every 2-second time intervals of the measurement period. These emission values were converted into emission factors and expressed in terms of gm sec^{-1} and gm km^{-1} as presented in Table 9.2. The tests were conducted during a.m. and p.m. periods: this will affect emissions, because of the difference in soak time of the engine during am and pm period of driving. This was part of the limitations of our data collection. It is observed that roughly speaking, the soak times for a.m. and p.m. are two hrs and five hrs respectively. All the emission data were averaged however, which will influence the accuracy of the results. Figure 9.2 shows HC emission, as an example of typical fluctuations of emission with time along the corridor. It should be noted that all emissions were generally higher during the engine start (i.e. during the cold start).

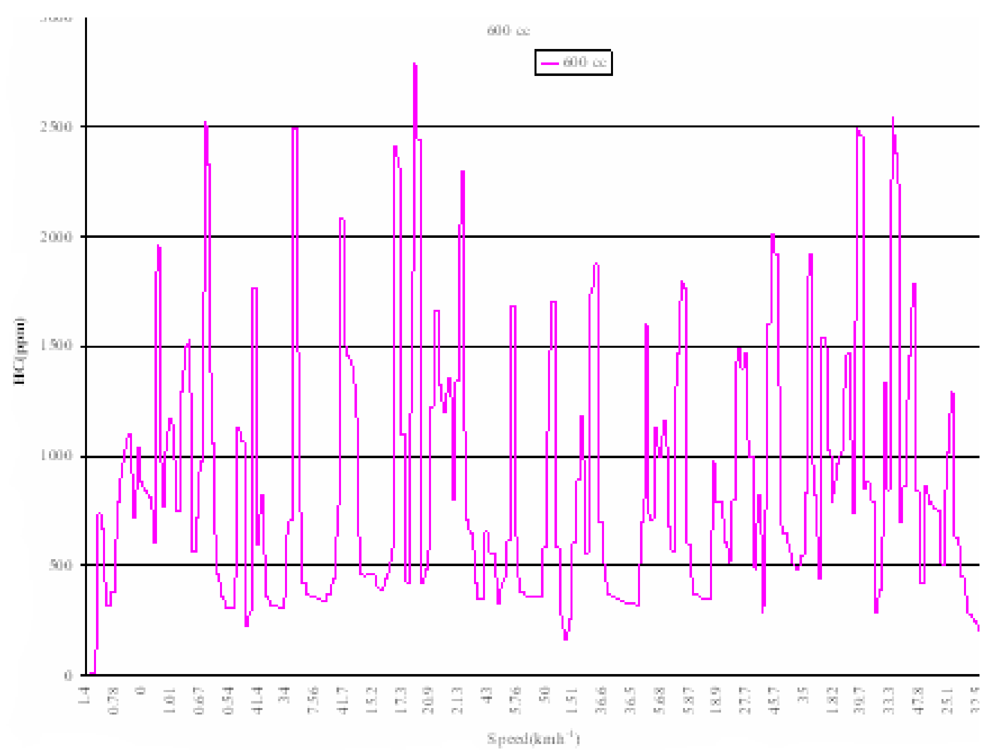


Figure 9.1 On board real world emissions of HC from 600 cc

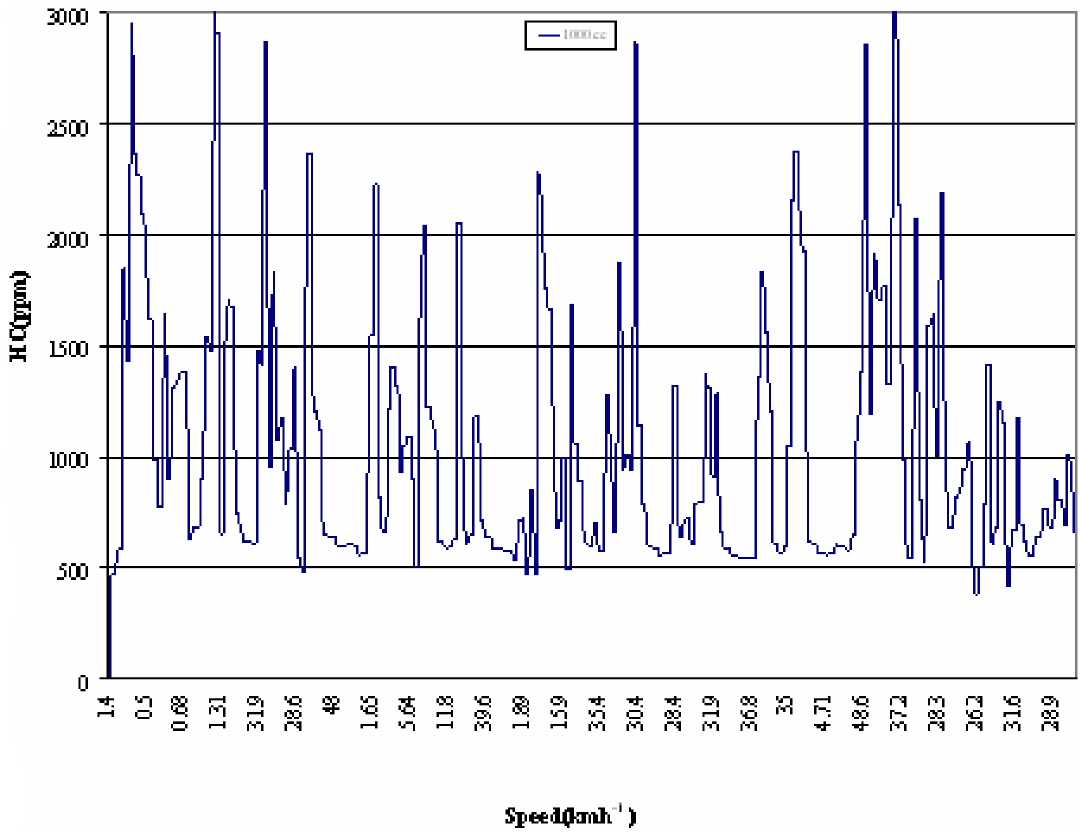


Figure 9.2 On board real world emissions of HC from 1000 cc

9.4 Average emissions

Table 9.2 shows the CO, HC, NO_X emissions presented as distance based (gm km^{-1}) and time based (gm sec^{-1}) of different engine sizes for each test drive. The average value as well as SD of the emission are 21.91 (5.3), 0.77 (0.052) and 0.063 (0.016) gm sec^{-1} (or equivalent in gm km^{-1}). This shows that there was no major fluctuation in driving pattern along the corridor. Standard deviation is a measure of the variability or dispersion of a population, a data set or a probability distribution. A low standard deviation indicates that the data points tend to be very close to the same value (the mean), while high standard deviation indicates that the data are ‘spread out’ over a large range of values.

Carbon monoxide (CO) is produced due to the incomplete oxidation of carbon during the process of combustion when any fuel is burned. Diesel, bio-diesel, gasoline, propane, natural gas, oil, wood and coal all produce carbon monoxide when burned. The highest CO emission was observed in the 4th test run while lowest was observed in the 1st test run. It was noticed that the average total CO emission was 21.9 gm sec^{-1} for 1000 cc, while it was 14 gm sec^{-1} for 600 cc. CO emissions for 1000 cc was 1.5 times higher than 600 cc. The reason for this seems to be the engine size of the vehicle and model year. Vehicle usage and age have significant impact on the emissions (Bin Okmyung, 2003). The 1000 cc motorcycle was 18 years old compared the 600 cc model, which was 5 years old. The 1000 cc motorcycle had a catalytic converter but this was not very effective in the urban environment due to cold starts, therefore it failed to meet the statutory requirement of CO emissions. CO emissions are also dependent on fuelling calibration and engine size and power (Bosteel, 2005).

Hydrocarbons (HC) are released into the atmosphere because of incomplete combustion of fossil fuels as well as fuel evaporation. Details of HC emissions results are provided in Table 9.2 on a gm km^{-1} basis. HC emission was not much affected by engine size. Hydrocarbon emissions are primarily associated with early part of the cycle before the catalyst becomes effective. It may be due to the cold start emission of both vehicles. HC levels are also associated with overrun on deceleration. There would be secondary air valve/injection.

Control of exhaust emissions depends on the method of injection and the point at which air enters the exhaust system. The first systems inject air very close to the engine, either in the cylinder head’s exhaust ports or in the exhaust manifold. The secondary injection system provides oxygen to oxidize (burn) unburned and partially burned fuel in the exhaust before its ejection from the tailpipe. There was significant such unburned and partially burned fuel in the exhaust of 1960s and early 1970s vehicles, and so secondary air injection significantly reduced tailpipe emissions. However, the extra heat of combustion, particularly with an excessively rich exhaust caused by misfiring or a maladjusted carburettor, tended to damage exhaust valves and could even be seen to cause the exhaust manifold to incandesce (Bosteels, 2005).

Nitrogen oxides (NO_X) are formed when nitrogen (N) and oxygen (O) are combined at high temperatures and pressure during the combustion of fuel. Due to the many compounds that are a part of NO_X (predominantly nitrogen dioxide and nitric oxide), the pollutant contributes to a wide variety of health and environmental problems. NOx is also a main component of ground-level ozone and contributes to global warming. Calculated emission factor of NO_X for both motorcycles are shown in Table 9.2.

Table 9.2 CO, HC and NO_X emission factors of test vehicles

Engine Size	Run no.	Total Emission (gm sec^{-1})			Total Emission (gm km^{-1})		
		CO	HC	NO_X	CO	HC	NO_X
1000 cc	1.0	14.76	0.27	0.08	1.89	0.04	0.01
	2.0	20.43	0.24	0.06	2.71	0.03	0.01
	3.0	16.13	0.20	0.04	4.02	0.05	0.01
	4.0	28.55	0.34	0.08	3.57	0.04	0.01
	5.0	27.92	0.34	0.07	3.51	0.04	0.01
	6.0	22.99	0.27	0.07	2.89	0.03	0.01
	7.0	22.60	0.25	0.05	2.81	0.03	0.01
Average of 1-7		21.91	0.27	0.06	3.06	0.04	0.01
Standard deviation (SD)		5.30	0.05	0.02	0.70	0.01	0.00
600 cc	1.0	12.40	0.31	0.03	1.53	0.04	0.00
	2.0	13.83	0.36	0.04	1.74	0.05	0.01
	3.0	16.33	0.36	0.04	2.04	0.05	0.01
	4.0	14.68	0.32	0.03	1.81	0.04	0.00
	5.0	13.50	0.32	0.02	1.68	0.04	0.00
Average of 1-5		14.15	0.33	0.03	1.76	0.04	0.00
Standard deviation (SD)		1.47	0.03	0.01	0.19	0.00	0.00

9.5 Relative influence of acceleration and speed on emission in actual driving conditions

Numerous variables influence vehicle energy and emission rates. These variables can be classified into six broad categories, as follows: travel-related, weather-related, vehicle-related, roadway-related, traffic-related, and driver-related factors; these are presented in Table 9.3. The travel-related factors account for the distance and number of trips travelled within an analysis period, while the weather-related factors account for temperature, humidity, and wind effects. Vehicle-related factors account for numerous variables including the engine size, the condition of the engine, whether the vehicle is equipped with a catalytic converter, whether the vehicle's air conditioning is functioning, and the soak time of the engine. The roadway-related factors account for the roadway grade and surface roughness while the traffic-related factors account for vehicle-to-vehicle and vehicle-to-control interaction. Finally, the driver-related factors account for differences in driver behaviour and aggressiveness[1].

Table 9.3 Factors influencing vehicle energy and emission rates

Variables	Factor
Travel Related	Distance, number of trips travelled, traffic volume, average speed, traffic composition
Weather	Temperature, humidity, wind effect
Roadway	Road grade, surface roughness, length, speed limit
Driver related	Difference in driver behaviour and aggressiveness
Vehicle Related	Engine size, condition of engine, vehicle after treatment technology, vehicle load and soaking time of engine

Source: Ahn (2002)

Data collected during different driving condition and different engine sizes provide a good knowledge of emissions and their instantaneous variation during driving cycles, it is possible to assess the impact of instantaneous speed and acceleration (Andre, 1997), but this is not directly usable because accelerations are not isolated events within traffic conditions, they are followed by deceleration and cruise phases. Therefore, joint distribution of acceleration/deceleration and speed was estimated for trip made along the test track.

1(http://filebox.vt.edu/users/hrakha/Publications/ASCE%20Hybrid%20Microscopic%20Energy%20&%20Emission%20Model.pdf).

9.5.1 *Speed and acceleration distributions*

Instantaneous emissions of four pollutants (CO, HC, NO_X and CO_2) for 12 sets of driving data were measured across the test corridor at 2-second time intervals. They were then expressed as functions of instantaneous speed and acceleration, using the joint distribution of the speed X acceleration product. They were stratified into seven speed classes, ranging from 0 to 60 km h^{-1}, and into seven acceleration/deceleration phases from -0.3 to 0.3 m sec^{-2}. The details of the percentage frequency are shown in Table 9.4.

Table 9.4 Joint probability of speed and acceleration

	Speed (km h^{-1})						
	Range	0-10	10-20	20-30	30-40	40-50	50-60
Deceleration (m sec^{-2})	< -0.3	0.94	0.38	6.97	0.00	9.79	0.00
	-0.20	2.26	0.00	11.68	0.00	0.00	0.38
	-0.10	6.78	0.00	0.00	16.38	0.00	0.00
Acceleration (m sec^{-2})	0.00	5.46	0.00	0.00	0.00	0.00	0.00
	0.10	1.51	0.00	0.00	0.00	0.00	0.00
	0.20	0.57	0.94	1.32	15.25	8.29	1.51
	0.30	0.38	9.23	0.00	0.00	0.00	0.00

It is quite clear from Figure 9.3 below that maximum probable speed was in the speed group of 30-40 km h^{-1}, while maximum probable positive acceleration was in the range of 0.2-0.3 m sec^{-2} and deceleration minimum was 0.1-0.2 m sec^{-2}. This can also be used to characterise the speed and acceleration pattern of the driving cycle of the test track. (Hung et al., 2007; Andre, 2004).

9.5.2 *Influence of instantaneous speed*

To investigate the influence of instantaneous speed on emissions, records of instantaneous emissions were grouped according to the instantaneous speed. The influence of speed was also observed on the different pollutants as presented in Figure 9.3. This Figure shows during 0-30 km h^{-1} there is a large reduction in CO, HC and NO_X emissions, and then there is slight increase of emission with the increase in speed, for the

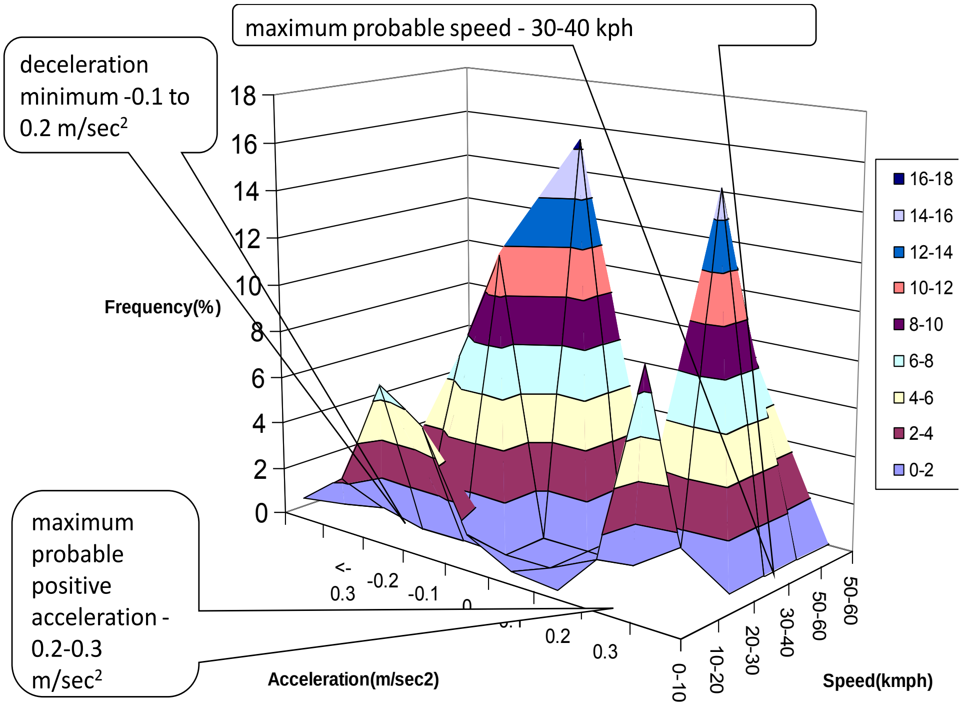


Figure 9.3 Speed acceleration frequency joint probability function

older motorcycles of engine size of 1000 cc. Newest motorcycles (600 cc) showed decrease in emissions with increase in instantaneous speed.

For the motorcycles (600 cc), the initial CO emissions were very high, possibly due to engine and technology (carburettor), and the cold start engine effect. The emission reduced with the increase in engine speed: this shows that burning efficiency improves after certain speed. However, for 600 cc engines a sudden decrease in emissions was observed at 10-20 km h^{-1}; this is due to the Euro 2 standard of the motorcycle. In addition, newer technology vehicles have overall lower emissions compared with older engines.

Table 9.5 Influence of instantaneous speed on emission

Engine size	Speed (km h^{-1})	CO (gm km^{-1})	HC (gm km^{-1})	NO_X (gm km^{-1})
1000 cc	0-10	25.73	6.43	0.23
	10-20	5.13	1.84	0.06
	20-30	0.02	0.01	0.00
	30-40	2.20	0.66	0.02
	40-50	1.68	0.60	0.02
600 cc	0-10	70.17	1.39	0.04
	10-20	2.55	0.07	0.00
	20-30	1.53	0.04	0.00
	30-40	1.08	0.03	0.00
	40-50	0.94	0.02	0.00

9.5.3 Correlation between emission factor and speed

Average speed used an important factor in emission modelling because emissions are strongly dependent on speed (Smith et al., 1995, André and Hammarström, 2000). Average speed is also an important variable in emission modelling because traffic emissions are strongly dependent on speed in a non-linear fashion. In this section relationships between different emissions and instantaneous speed (grouped into 10 km h^{-1} speed intervals) have been developed along the corridor (Figure 9.4).

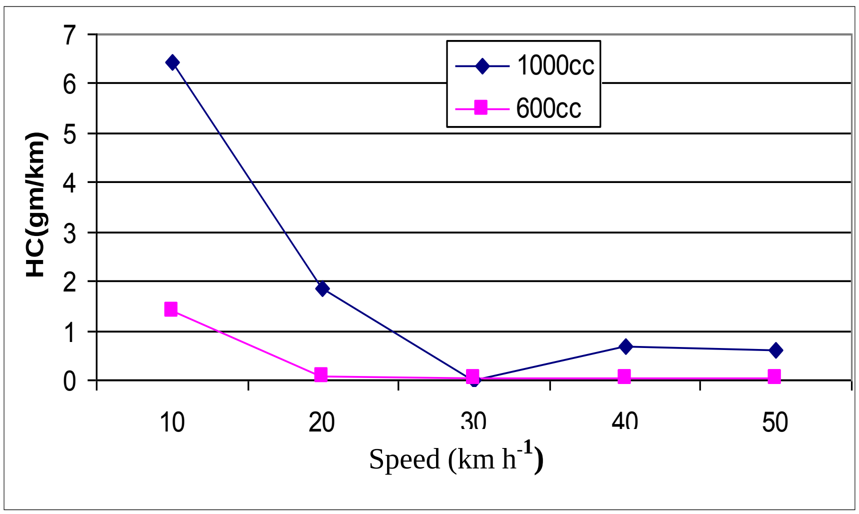


Figure 9.4 Influence of speed on HC emissions

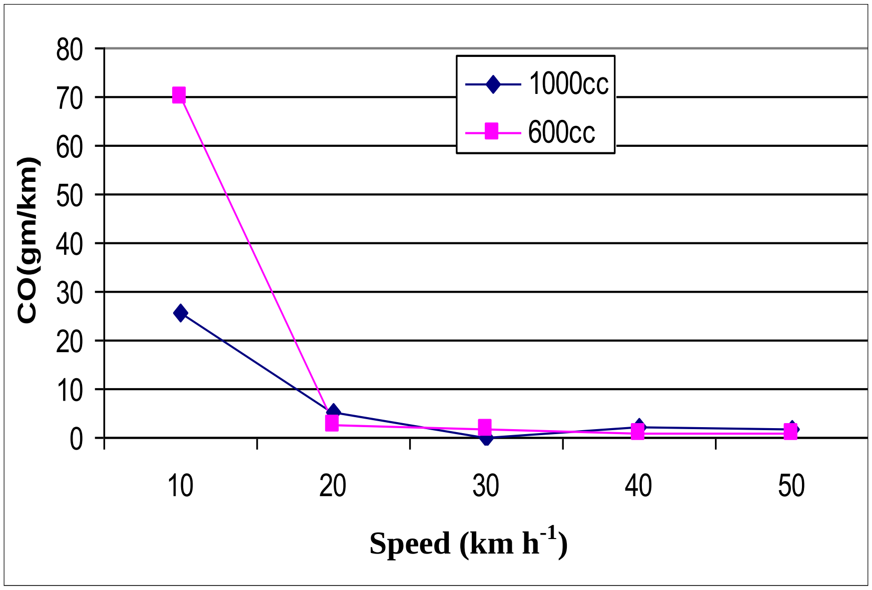


Figure 9.5 Influence of speed on CO emissions

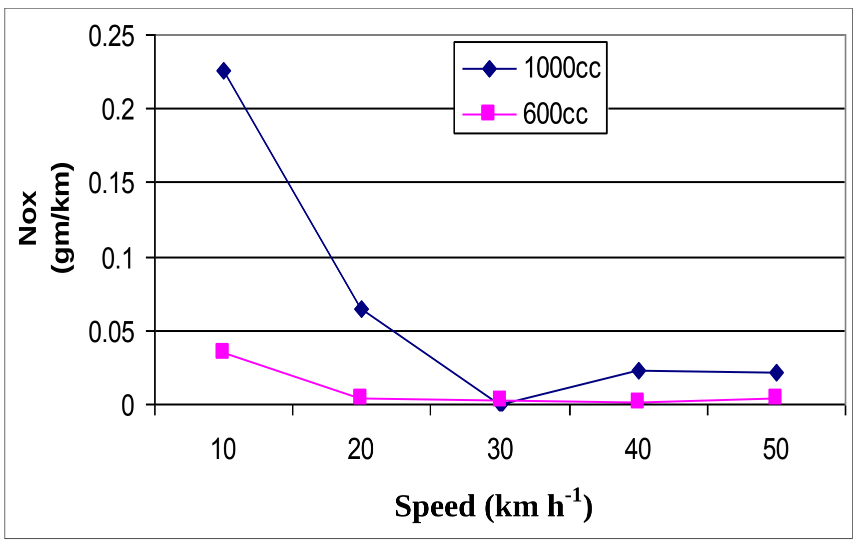


Figure 9.6 Influence of speed on NO_X emission

The emission model is developed based on the instantaneous speed of motorcycles and emissions. Table 9.5 shows that generally emissions are higher at the very low speeds, and decreases as speed increases up to 30 km h^{-1}, and then emissions start to increase, which indicates that this has implication on speed enforcements for motorcycles in order to reduce emissions. Furthermore, these empirical formulae have been developed to calibrate regression models for different pollutant emissions as functions of instantaneous speed (detailed in Table 9.6). R^2 is also calculated for each model: in regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. R^2 is a statistical measure that will give an indication about the goodness of fit of a model or formulae. A R^2 of 1.0 means that the regression line perfectly fits the data. In this modelling, R^2 is found to be greater than 0.86, which shows higher goodness of fit of the data.

Table 9.6 Regression models for different pollutant emissions

Engine Size	(gm km $^{-1}$)	Model	R^2
600 cc	HC	$0.0017*V^2-0.1234*V+2.4083$	0.87
	CO	$0.0914*V^2-6.646*V+126.13$	0.99
	NOx	$0.00004*V^2-0.003*V+0.056$	0.74
1000 cc	HC	$0.0109*V^2-0.7423*V+12.597$	0.98
	CO	$0.0473*V^2-3.1167*V+51.088$	0.96
	NOx	$0.0004*V^2-0.025*V+0.4326$	0.97

Where V (km h^{-1}) = speed of motorcycle

Higher levels of NO_X emissions are the result of leaner air/fuel ratios and the resulting higher combustion temperatures. NO_X emissions peak near stoichiometry ratio (chemically balanced mixture of air/fuel ratio). Diluting the air/fuel mixture with exhaust gases reduces peak combustion temperatures and NO_X formation reduces. It reduces up to speeds of 30 km h^{-1}, then increases again (see Table 9.5). Table 9.6 represents a crude equation of emissions as a function of instantaneous speed based on local traffic conditions in Edinburgh city centre and on selected routes. This could be used as an alternative to the TRL emission coefficient. It is important here to note the need of local emission models for air pollution control Authority. Speed is a highly sensitive parameter in emission modelling: inaccurate speed predictions may have a strong effect on predicted emissions. For instance, EPA (1993) conducted a sensitivity analysis on the average speed emission model MOBILE 5 and found that an error of 5 km h^{-1} in the estimated value of speed for a freeway caused a 42% difference in CO emission predictions due to the non-linear relationship between emissions and speed. There have been efforts to improve estimates of mean link speed from (static) macroscopic traffic models using traffic data that are relatively easy to obtain (Dowling and Skabardonis, 1992; Nesamani et al., 2007).

9.6 Modelling modal pollutants emissions

Mobile source emission-factors can only be used to predict emission inventories for large regional areas; they are not well suited for evaluating operational improvements that are microscopic in nature, such as ramp metering, signal coordination and many application over intelligent transportation system (ITS) strategies (NCHRP Project, 2000). In addition to regional types of mobile source model, we need the model to take into account the mode of operation of vehicles, i.e., emissions that are directly related to vehicle operating modes such as idle, steady-state cruise, various levels of acceleration/deceleration, etc.

A convenient method to characterize vehicle-operating modes is to set up a speed/acceleration matrix, which forms number of bins. With such a matrix, it is possible to associate emissions with speed in each bin/class of range or mode. This emissions matrix can then be combined with a time matrix for the vehicle activities broken down into the different driving modes. The result is the total amount of emissions produced for the specified vehicle activity with the associated emissions matrix. However, there may still be other factors that affect emissions, which are not included in this analysis such as gradients or use of accessories. There are other approaches, which can be used for modal emission by assessing emission maps, or the physical power demand based modal modelling (Barth, 1996). In this research, the modal emission modelling approach is employed using speed and acceleration data from the field. These data were processed and synchronised with analyser data (for details see Section 7.3.7).

Furthermore, driving conditions data were classified into four vehicle-operating modes in the following criteria

- Deceleration ($0 < -0.1$ m sec^{-2}),

- Idling (0-3 km h^{-1}),
- Cruising (> -0.1, < 0.1 m sec^{-2} > 0-3 km h^{-1})
- and acceleration (> 0.1 m sec^{-2}).

The modal emission for CO, HC and NO_X are shown in Table 9.7 for acceleration, deceleration, cruising and idling modes. Higher percentages of total emissions were observed during deceleration and acceleration driving modes respectively for both engine sizes. Lowest emissions were observed in idling and cruising driving modes. The details are discussed as follows.

Table 9.7 Observed total emissions in vehicle operating modes

Engine Size cc	Vehicle operating mode	CO (%)	HC (%)	NO_X (%)
1000	Deceleration	49.28	45.27	47.85
	Idling	2.56	11.61	7.42
	Cruise	5.79	4.85	5.56
	Acceleration	42.37	38.28	39.18
600	Deceleration	56.95	50.95	56.71
	Idling	1.78	3.08	2.89
	Cruise	5.75	5.65	7.42
	Acceleration	35.53	40.32	32.98

9.6.1 Observed emissions in deceleration

The EMDC has a frequent number of decelerations. During deceleration modes, the engine does not necessarily generate power. However, the fuel flow rate cannot be stopped immediately when transferring to deceleration modes from acceleration and cruising. Excess fuel thus continues flowing at the early phase of deceleration (Carlock, M.A, 1992). The CO, HC, NO_X emissions of the 1000 cc and 600 cc in deceleration modes were 49-56%, 45-51%, 48-56.7% of total emission respectively.

9.6.2 Observed emissions in idling

The urban EMDC has lower time spent in idling and cruising due to typical driving characteristics. The reason is that Edinburgh has rolling terrain and signal time is controlled by SCOOT (A computerised signal controller system). Apart from that, motorcycles can filter into traffic during while manoeuvering, so less time is spent in idling mode. As a result, a small amount of fuel is needed to maintain engine operation. Hence, the total idling emissions and cruise emissions are significantly lower than other driving modes. CO emission in idling mode for 1000 cc motorcycles was 2.6% of total emissions, though it was 1.8% for 600 cc. HC and NO_X emissions for 1000 cc were significantly higher (12% and 7.5% respectively) as compared to 600 cc (3% and 2.88% respectively).

9.6.3 Observed emissions in acceleration

In the acceleration process, the engine needs more fuel power to generate enough power to accelerate. The higher the acceleration rate, the more fuel is needed, therefore fuel consumption increases. It can be seen from Table 9.7 total emissions of CO, HC and NO_X for 1000 cc are 42%, 38%, and 39.16% respectively, while total emissions for 600 cc are 35, 40 and 32% respectively. The emissions of CO and NO_X were found to be lower in acceleration modes for 600 cc.

9.6.4 Comparisons of observed emissions between different driving modes

The EMDC characteristic has a higher percentage of time spent in deceleration than any other driving modes. This was reflected in the emissions also. For example, for 1000 cc total CO emissions were found to be more in deceleration modes. Total observed emissions of CO in deceleration modes were 7% more than acceleration, which is also true for HC. This was also 47% more than in cruise and idling modes.

For the engine of 600 cc, total HC emission in deceleration modes was found to be 10% more than acceleration modes, while total HC emission in idling and cruise modes for the larger engine size of 1000 cc was more than the 600 cc engines, demonstrating the effect of engine size on emissions. For 1000 cc engines total NO_X emission in deceleration modes was found to be 8% more than acceleration, whereas it was 40%

more than cruise and idling modes. For 600 cc engines NO_X emission in deceleration modes were found to be 23% higher than acceleration modes. Emissions in deceleration mode were found to be 40-50% higher than cruising and idling modes.

9.7 Effects of driving modes on emissions

Considerable emissions were observed in acceleration and deceleration modes (accounting for more than 93% of the total emissions where the average speed run along the test route in city centre was found to be 23 km h^{-1}). The relationship between total emissions and percentage of time spent in different vehicle operating modes for different day are shown in Figure 9.7-9.9. Total CO (gm sec^{-1}) decreases with the increase in the time spent in deceleration. Increase in total CO emission was found with increase in time spent in acceleration, idling increases. Time spent in decelerations varies in the test run between 47- 53%; overall time spent in accelerations varies between 39-44%, whereas time spent in idling activity varied from 1 to 4.5%.

For HC (gm sec^{-1}) emissions decrease with the increase in time spent in deceleration, where as it increases in acceleration and idling. In contrast to the above, NO_X emissions increase with time spent in deceleration and cruising, whereas it decreases with time spent in acceleration, whilst NO_X (gm sec^{-1}) initially decreases, then starts to increase after a certain time interval. Standard deviation (SD) of CO emissions varies from 3 to 0.5 for different operating modes, whereas SD for HC ranged from 0.06 to 1.93 in different operating modes. For NO_X, it was 0.001 to 1.931. This shows that CO emission is more sensitive to vehicle operating modes and had a larger range of standard deviation than HC and NO_X.

This approach is very important and relevant, especially to the driving cycle. However, the results should be treated with care as they were obtained from a very limited number of runs. It is strongly recommended to carry out further research with a much larger dataset to verify these models.

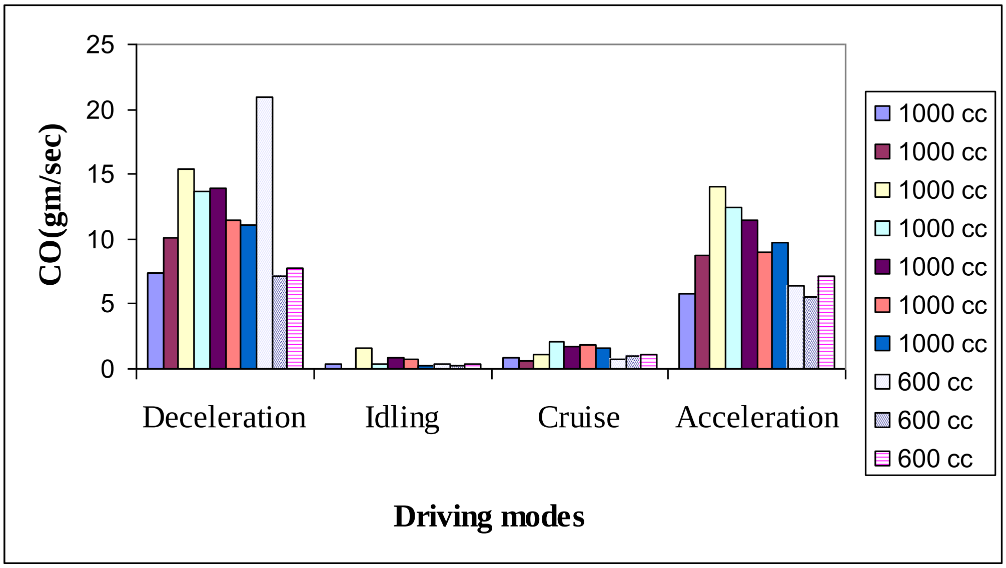


Figure 9.7 Comparison of CO emissions in different driving modes

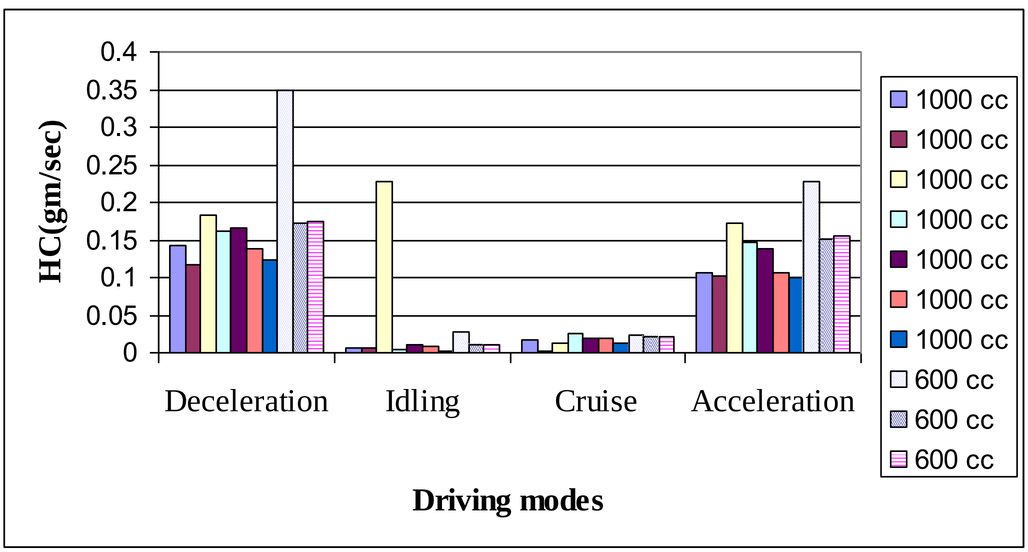


Figure 9.8 Comparison of HC emission in different driving modes

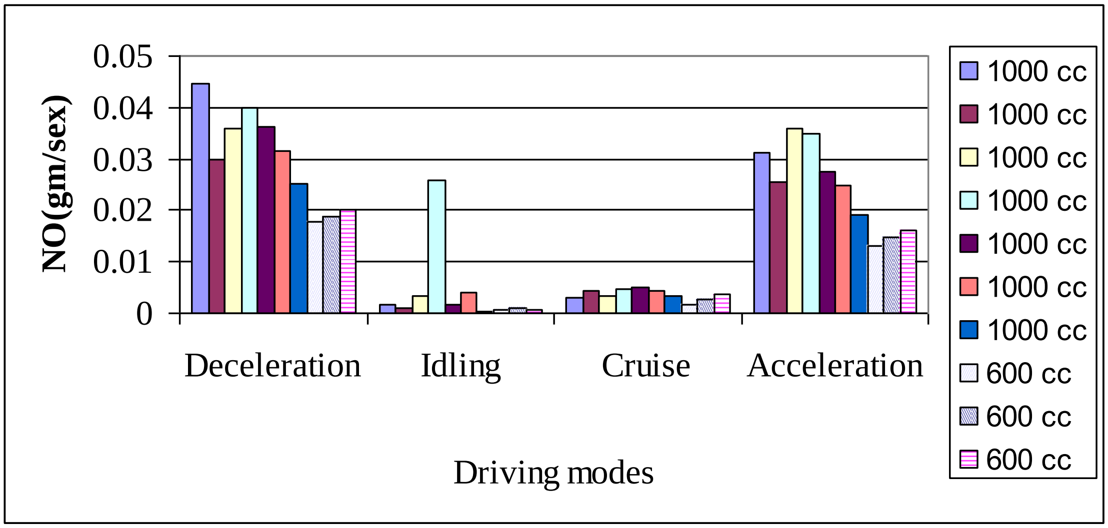


Figure 9.9 Comparison of NO_X emission in different driving modes

9.8 Modelling emissions based on the time spent in driving modes

Although emission models (see for example Andre (2009), Rapone (2005), and Frey (2001) and Appendix 9.3) are complex (due to the large number of equations and variables), they are useful tools for the understanding and prediction of future emissions under various scenarios. They can demonstrate their ability to discriminate the emissions in a satisfactory way through dynamic related parameters and in particular through time spent in different vehicle operating modes of the driving cycle, such as time spent in idling cruise, acceleration and deceleration. Many emission models have been developed to obtain emission rates in the real world based on the relationship between the average speed v, the mean of square and cubic speeds (e.g. v^2 and v^3, where v is speed), the average of the speed x acceleration product (e.g. va, where a is acceleration), the inverse of the cycle distance, idling, and total running durations (e.g. 1/d, Where d is distance Ti- idle time and Tr- running time), and emission [(Andre (2009), Rapone (2005), and Frey (2001)].

In this work, due to limitations of sample sizes and time it was not possible to calibrate statistically significant results from this modelling exercise (the limited results from this modelling task are presented in Appendix 9.3).

Evaluation of the percentage of time each driver spent in each driving event or 'mode' was done by classifying the data from the different test runs into acceleration, deceleration, idling, and cruising modes in this study. These data, while not necessarily directly correlated to exhaust emissions for motorcycle due to transient operation, are nevertheless useful for understanding urban driving patterns. Fractions of the time spent in each operating mode and the average emission factors, were calculated for each pollutant. Relationships were found between total emission per seconds and percentage time spent for driving model (Appendix 9.3).

9.9 Emission measurements from laboratory

Table 9.8 shows emission factors which are obtained from the laboratory measurements (Appendix 9.2). The methodology for emission measurement from laboratory has been discussed in Chapter 8. Fourteen different tests were carried out on different day for the various pollutants, such as CO, HC, NO_X and CO_2, using speed and acceleration characteristics of number of driving cycles. Driving cycles included ECE 40, EMDC urban and rural and WMTC cycles. The WMTC cycle consists of three parts: WMTC Part 1 (urban), WMTC Part 2 (rural highway) and WMTC Part 3 (motorway). The discussion of data obtained from those test are presented below.

9.9.1 CO emission factor

The greatest differences in CO emissions factor came from the two hot and cold start cycles (EMDC rural & EMDC urban) (see Table 9.8). An engine size of 600 cc contributed very low CO emissions compared to 1000 cc. The CO emission factor for 600 cc was five times lower than 1000 cc motorcycle. The average emission factor for 600 cc was 16.81 gm km^{-1} in comparison to 38.86 gm km^{-1} of 1000 cc motorcycles;

however standard deviation of 600 cc was higher (9.4 gm km^{-1}) compared to 1000 cc motorcycle (3.92 gm km^{-1}) measured in different driving cycles. For 600 cc, WMTC Part 3 showed a higher CO emission factor, while the EMDC rural showed the lowest value of emission factor. For 1000 cc engines the urban EMDC showed the highest emission factor (44.1 gm km^{-1}) among all the driving cycle, where as rural EMDC showed lower emission factor (36.9 gm km^{-1}) (see Figure 9.10). Emission factors from EMDC rural were lower for both type of engine.

Table 9.8 Emission factors obtained from the laboratory measurements

Pollutant (gm/km)	Engine size cc	EMDC urban	EMDC rural	ECE 40 measured	WMTC measured Part 1	WMTC measured Part 2	WMTC measured Part 3	Average	Std dev
CO	600	13.10	9.40	15.90	10.00	17.60	34.90	16.81	9.42
	1000	44.10	36.90	34.20	36.80	43.20	38.00	38.86	3.92
HC	600	4.40	1.60	2.40	3.00	1.90	2.10	2.56	1.01
	1000	3.70	1.50	2.80	3.00	1.80	1.20	2.33	0.97
NO_X	600	0.20	0.10	0.10	0.10	0.10	0.20	0.13	0.05
	1000	0.30	0.10	0.20	0.10	0.20	0.60	0.25	0.18

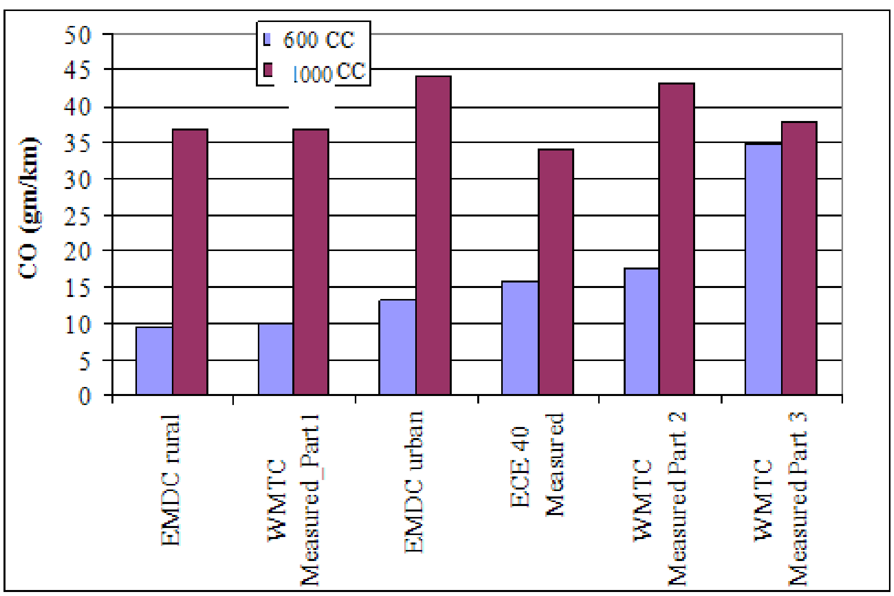


Figure 9.10 CO emissions of 600 cc and 1000 cc relative to EMDC, WMTC and ECE driving cycle

9.9.2 HC emission factor

Figure 9.11 illustrates that the greatest differences in HC emissions came from the two cold start and hot start cycles (EMDC urban and WMTC part 3). An engine size of 1000 cc contributed very low HC emissions compared to 600 cc. The average emission factor for 600 cc was 2.56 gm km^{-1} in comparison to 2.33 gm km^{-1} of 1000 cc overall driving cycles motorcycles. This shows that the smaller engine size did not perform well with HC. Also, standard deviation of 600 cc was higher (1.017 gm km^{-1}) with respect to 1000 cc motorcycles (0.979 gm km^{-1}). EMDC urban showed a highest HC emission factor (3.7 gm km^{-1}) for 1000 cc, while WMTC showed the lowest value of emission factor (1.2 gm km^{-1}). For 600 cc engines EMDC urban showed highest emission factor (4.4 gm km^{-1}) and EMDC rural showed lowest emission factor (1.6 gm km^{-1}).

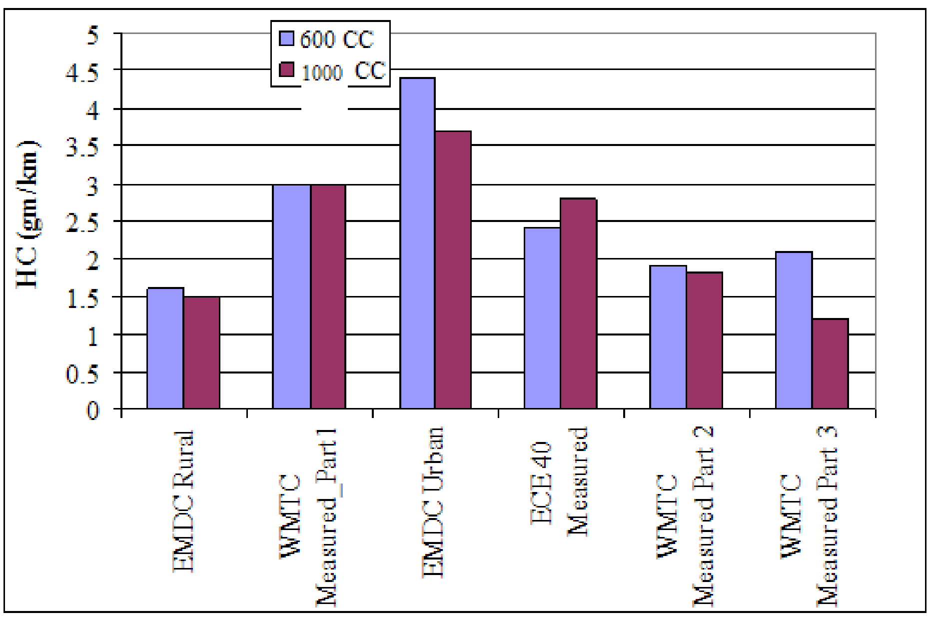


Figure 9.11 HC emissions of 600 cc and 1000 cc relative to EMDC, WMTC and ECE driving cycles

9.9.3 NO_X emission factor

Figure 9.12 illustrates that there were no great difference in NO_X emissions among the driving cycles with the exception of the hot start cycle WMTC measured part 3. An engine size of 1000 cc found double of NO_X emissions factors compared to 600 cc. The average emission factor for 600 cc was 0.133 gm km^{-1} in comparison to 0.25 gm km^{-1} for 1000 cc motorcycles measured over driving cycles. This shows that the small engine size did not perform well with HC. Also the standard deviation of 600 cc was lower (0.05 gm km^{-1}) with respect to 1000 cc motorcycle (0.18 gm km^{-1}). For 1000, cc engines the EMDC urban showed a lowest NO_X emission factor (0.1 gm km^{-1}), while WMTC Measured showed the highest value of emission factor (0.6 gm km^{-1}). For 600 cc, engines the EMDC urban showed a highest emission factor (0.2 gm km^{-1}) and EMDC rural showed a lowest emission factor (0.1 gm km^{-1}).

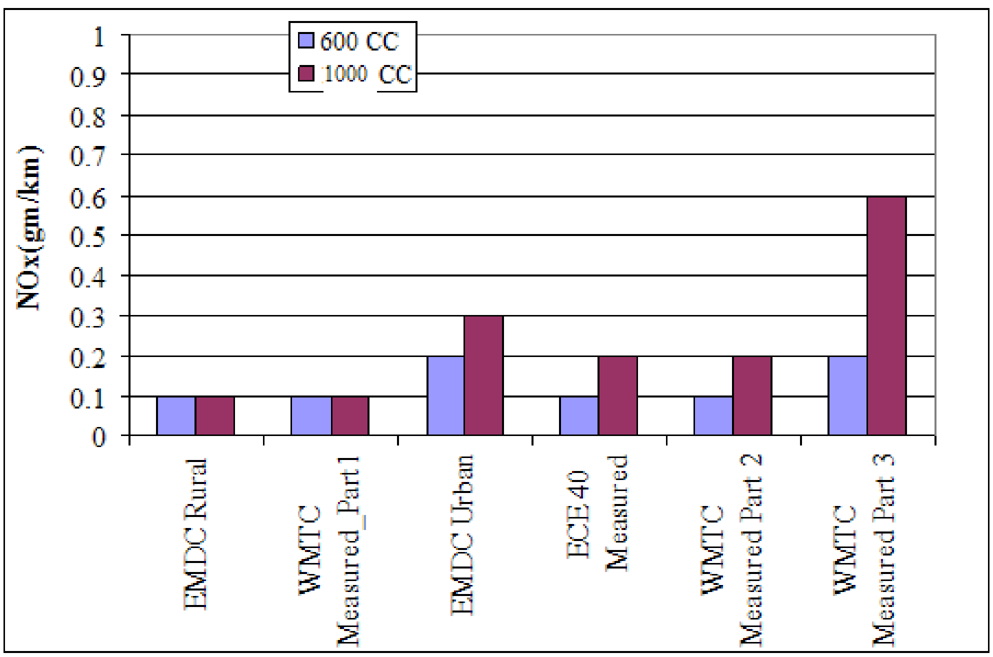


Figure 9.12 NO_X emissions of 600 cc and 1000 cc relative to EMDC, WMTC and ECE driving cycles

Typical examples of the recorded data for HC, CO and NO_X on the EMDC driving cycles obtained from laboratory are presented in Figure 9.13-15. In all cases, it was found that HC and CO emission exceeded the target vales of the EMDC driving cycle. It seems that none of the vehicles complies with certification standards when they are subjected to the local driving cycle of Edinburgh.

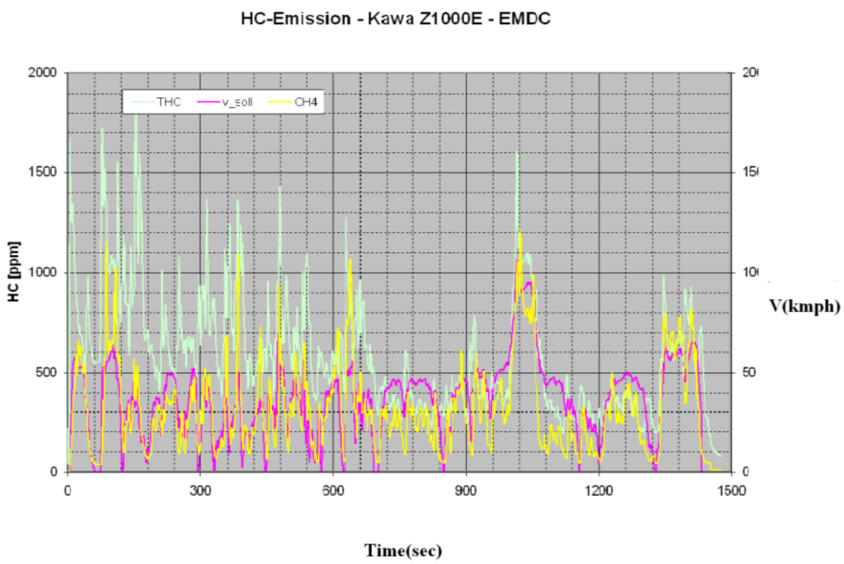


Figure 9.13 HC and methane emissions on Kawasaki 1000 cc for EMDC driving cycle from recorder in laboratory

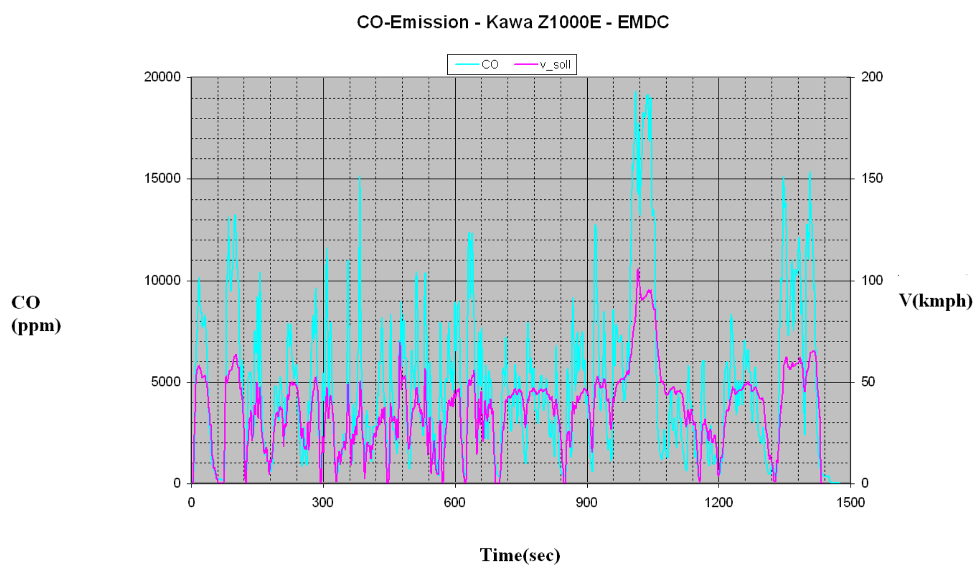


Figure 9.14 CO emissions on EMDC driving cycle from recorder in laboratory

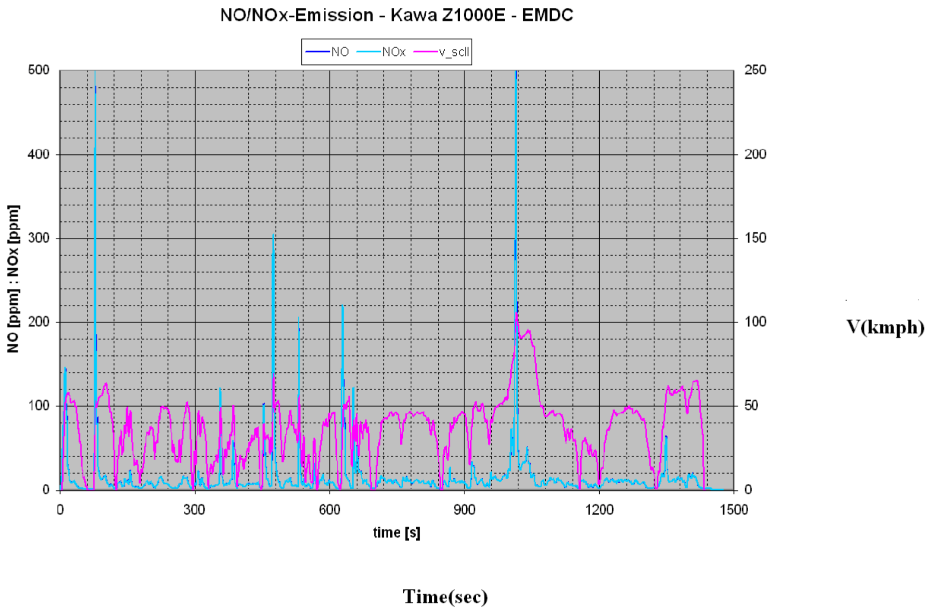


Figure 9.15 NO_X emissions on EMDC driving cycle from recorder in laboratory

9.10 Summary and conclusions

Real-world onboard emission measurement and laboratory emissions are used to measure emission factors. Both methods have their advantages and limitations. Instead, it can be argued that modelling individual vehicle fuel consumption and emissions coupled with the modelling of vehicle kinematics on an urban network could result in more reliable evaluations of operational-level environment impacts. Twelve test runs of onboard measurement and 14 laboratory tests were made. Results compared to measurements are somewhat disappointing in absence of accurate measurement of fuel. The influence of onboard emissions with speed and the effect of driving modes on emissions were modelled. Laboratory measurements give the comparison of emissions across different driving cycles such as ECE, WMTC and EMDC rural, while onboard emissions provide improvement of instantaneous emission modelling to improve quality of emission forecasts according to driving kinematics (i.e. speed and acceleration). To improve the existing instantaneous emission models, some preconditioning must be fulfilled: the emission signals should be measured on a 10 Hz basis, due to their frequency content. Additionally, the transport dynamics from the engine to the onboard analysers must be compensated by time-varying approaches. A limited number of test vehicles may not reflect the whole traffic fleet, but owing to the constraints of resources and time it was a feasible solution to understand the emission patterns of motorcycles in different driving cycles.

CHAPTER 10 DEVELOPING MOTORCYCLE DRIVING CYCLE USING MICRO-SIMULATION MODEL (VISSIM)

10.1 Introduction

Modelling individual vehicle driving cycles requires the speed of vehicles on a second-by-second basis. Traffic micro-simulation has been used in assessing the traffic performance of highway and street systems, transit and pedestrians and other expanded applications in transportation engineering and planning practice (Dowling, 2005). VISSIM is a micro-simulation software that is being used by different regions to analyse multi-interaction of transportation systems. However, no previous research has been undertaken to calibrate the driving cycle using micro simulation; therefore, it is not yet known how well traffic conditions in local environments can be represented using micro-simulation models.

This chapter discusses the adoption and analysis of the micro-simulation commercial software (VISSIM) and assesses its ability to represent the driving conditions of motorcycles in urban network conditions, taking a short section in Edinburgh as a case study. One test corridor is defined in the Air Quality Management Area (AQMA) of Edinburgh City centre, similar to the onboard measurement. Data collection using video recording and other secondary sources (e.g. TRL and ECC) have been utilised. The micro-simulation model has been calibrated using goodness of fit expressed as GEH and validated using different sets of real-world data for verification.

10.2 Overall model structure

So far, many traffic simulation models have been used in combination with various statistical methods to quantify the traffic emissions. However, the results from such an approach are not very accurate nor can they capture the characteristics of dynamic traffic fluctuations, especially of the motorcycles (Lee, 2008). Therefore, it is necessary to develop a microscopic simulation platform (Model) that can capture the dynamic traffic flows for estimating vehicle emissions, especially for motorcycles, which can then be used to evaluate the impact of the real-world traffic on emissions.

To characterize the driving cycle for motorcycle emissions, information on the traffic flow characteristics within the network to be modelled are required. This information includes the speed and acceleration of vehicles in the system. Network information needed for VISSIM includes road geometry, junction details, signal systems, vehicle types (e.g. cars versus heavy-duty vehicles), traffic volumes, and its composition. Microscopic simulation models provide vehicle speeds on a second-by-second basis, allowing detailed characterization of vehicle accelerations and decelerations required to develop driving cycle.

The VISSIM traffic simulation model is used to obtain the driving cycle that provides some advantages over many other traffic simulation models since it is based on human psychology and behaviour, and it includes a number of driving behaviour parameters (Algers, 1997). The actual movements of the vehicles in VISSIM are based on behavioural assumptions regarding the desired speed and gap acceptance of drivers. As an initial assumption, vehicles follow each other with the same speed. If a vehicle is travelling below the desired speed, it will accelerate to that speed using the maximum possible acceleration for the given speed and vehicle type. As the vehicle closes on any vehicle in front, the vehicle will after a slight reaction delay, decelerate to match the speed of the vehicle being followed. Should the desired gap distance be too small then the vehicle will react to avoid an accident by a sharp reduction in speed.

Lane changing movements are also based on human decisions that are influenced by the perceptions of surrounding vehicles in a similar fashion. These movements are based upon a natural distribution of various behavioural elements. These include differences in driving abilities, human perception, desired safety and speed and the relative levels of driver aggressiveness characterised by different maximum values for accelerations and decelerations. Such phenomena are normally distributed within the model, allowing the random selection of various values during the simulation process (Reiter, 1994).

The outputs from the VISSIM model are the instantaneous vehicle position, the vehicle speed, vehicle acceleration and many other parameters. These outputs are then used in this research to estimate the driving cycle as well as estimate the emissions using some NAEI emission factors. These types of modelling tools are found to be suited to the assessment of changes in driving styles in addition to simple changes in average speeds. The modelling structure for motorcycle emissions through micro-simulation has been depicted graphically in Figure 10.1. The structure shows that data related to network, signal, traffic volume, and vehicle characteristics are provided as major inputs to the VISSIM micro-simulation model. Once these inputs are provided then instantaneous speeds with respect to, time can be obtained as outputs for the emission estimation.

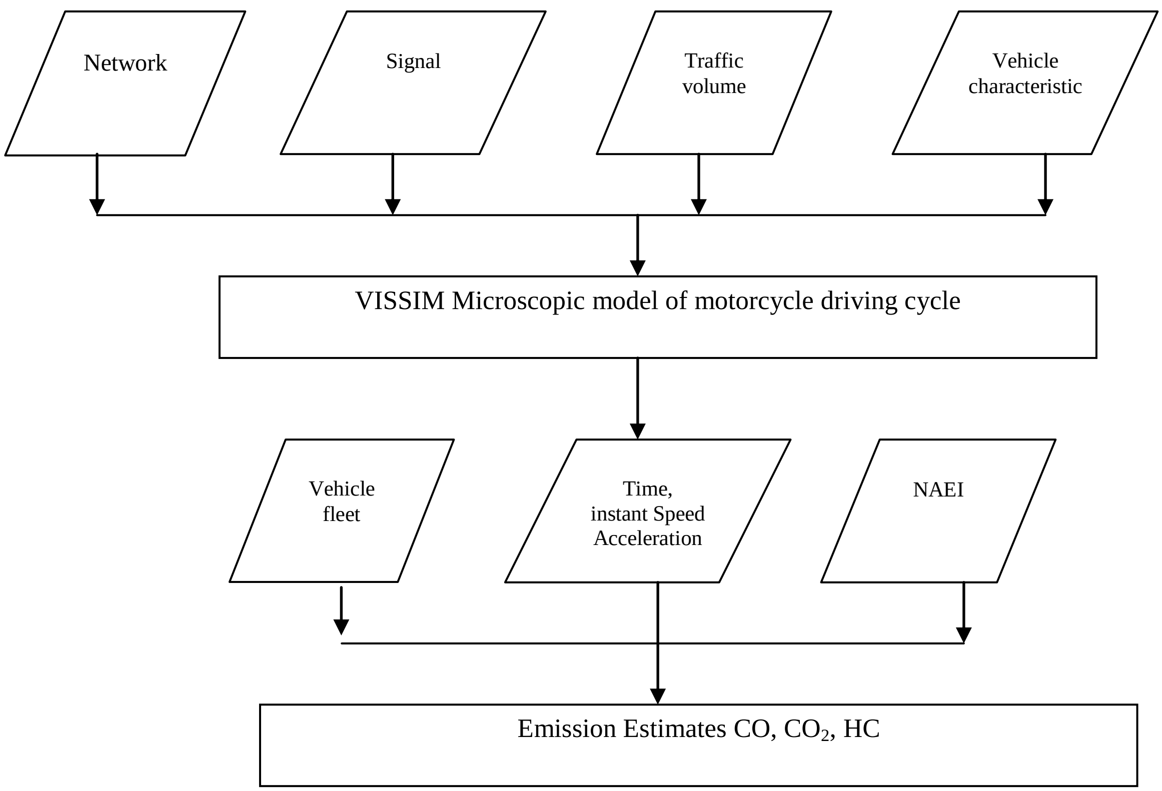


Figure 10.1 Structure of modelling the driving cycle of traffic corridor and an emission estimation using VISSIM

10.2.1 Development of microscopic traffic emission simulation platform

(a) Driving characteristics of motorcycles

The way motorcycles move is not the same as cars, which usually follow one after another along traffic lanes. Because of their characteristics, the movement of motorcycles is a two-dimensional movement, which includes longitudinal and lateral movement. The longitudinal movement contributes to forward movement and lateral movements are used to take up appropriate positions across the lane. Motorcycles can get longitudinal gap to accelerate their speed by lateral movements for overtaking (Lee, 2008).

The motorcycle traffic flow is influenced by driver characteristics, vehicle interactions and the external environment, all of which the proposed model will take into account. In the proposed model, driver characteristics include desired speed and the maximum acceleration and deceleration of a vehicle. The vehicle interactions include longitudinal and lateral movements. The external environment includes creation of motorcycle lanes near the stop line. The typical example of such movement is presented by Figure 10.2.

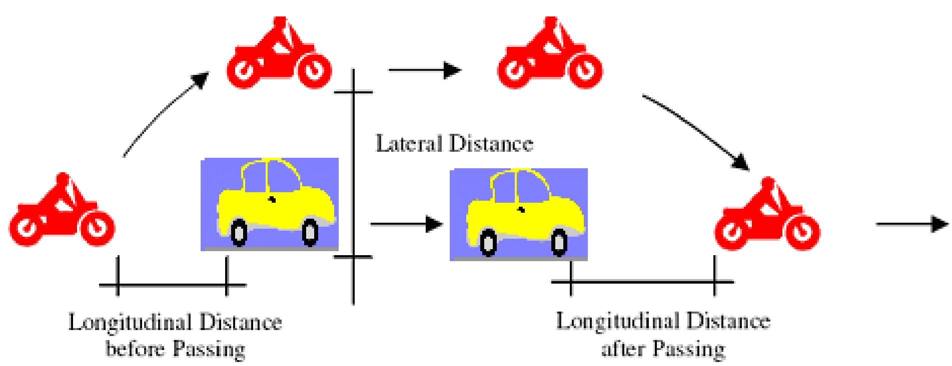


Figure 10.2 Passing manoeuvre of motorcycle

In the car-following model, the longitudinal and lateral movement of motorcycles will be covered in following and lateral the driver behaviour parameters in VISSIM.

Other factors like lane change and signal control will be included in external influences in the movement models. The motorcycle traffic can be significantly affected by many disturbances. This model focused firstly on motorcycle vehicle in traffic on a pilot case for the link on Gorgie Road. This model is further extended for the AQMA area. Finally, the output from a microscopic traffic simulation platform was integrated with NAEI database.

10.2.2 Types of data required for VISSIM model

(a) Base vehicle data

Vehicles with similar technical characteristics and physical driving behaviour can be classified into different groups. Typically, these types are as follows by default: car, LGV, HGV (truck), bus, articulated bus, tram, bike, pedestrian. It should be noted that motorcycle is not a default class: one or more vehicle types are combined in one vehicle class. Speeds, evaluations, route choice behaviour and certain other network elements refer to vehicle classes. By default, one vehicle class refers to one vehicle type with the same name. More than one vehicle type is to be included in a vehicle class if they incorporate a similar general driving behaviour but have different vehicle characteristics (e.g. acceleration values). If only the shape and length of a vehicle is different, they can be placed in the same type using the vehicle model and colour distributions.

Example 1: The models ‘Car 1’ to ‘Car 6’ refer to different models with different vehicle length yet similar driving behaviour. Therefore, they can be placed into one vehicle type using a model distribution with the six different models.

Example 2: Standard and articulated buses only differ in length, thus they can be placed into one type with a distribution of two models. Exception: when these two bus types need to be used in different transit routes then they need to be defined as two separate vehicle types. A motorcycle has been created on bike characteristic available as default for our study.

Preset static categories of vehicles that incorporate similar vehicle interaction (e.g. the vehicle category ‘tram’ does not allow for lane changes on multi-lane links and does not oscillate around its desired speed). Every vehicle type is to be assigned to a vehicle category. However, there is no special provision or default function of motorcycle model or length in VISSIM, though for this study the vehicle type ‘bike’ was considered appropriate for creating the base for motorcycle. Motorcycles also have a similar style of travelling along the routes except with higher rate of acceleration and deceleration.

VISSIM does not use a single acceleration and deceleration value but uses functions to represent the differences in a driver’s behaviour. Acceleration and deceleration are functions of the driving speed. In VISSIM, each vehicle type has two acceleration and two deceleration functions defined (i.e. maximum and desired acceleration and maximum and desired deceleration):

- Maximum acceleration: This is technically feasible acceleration exceeding the desired acceleration and is required to maintain speed on slopes.
- Maximum deceleration: This is the maximum technically feasible deceleration adjusted on slopes by 0.1 m s^{-2} for each percent of positive gradient and -0.1 m s^{-2} for each percent of negative gradient (see VISSIM Manual, 2008).

Desired deceleration is caused by the desired speed decision. The various reasons for this are as follows:

- stop & go traffic, when closing up to a preceding vehicle,
- insufficient lateral distance for overtaking within the lane,
- towards an emergency stop position (route),
- for co-operative braking (in this case 50% of the vehicle’s own desired deceleration is used as the maximum reasonable deceleration for the decision, in the case an indicating vehicle may change from the neighbouring lane to the vehicle’s lane).

In any other case, the parameters of the car-following model are relevant. These functions are predefined but can be edited for each of the default vehicle types in

VISSIM. Figure 10.3 shows a typical case of maximum and desired acceleration distribution for motorcycles. A range of parameters in VISSIM is defined as distributions rather than fixed values that reflect the stochastic nature of traffic situations realistically. Most of the distributions are handled similarly and it is possible to use any empirical or stochastic data for definition. All distributions can be accessed by Base Data – Distributions in the menu. Figures 10.4 a and b show an example of speed and desired deceleration for motorcycle.

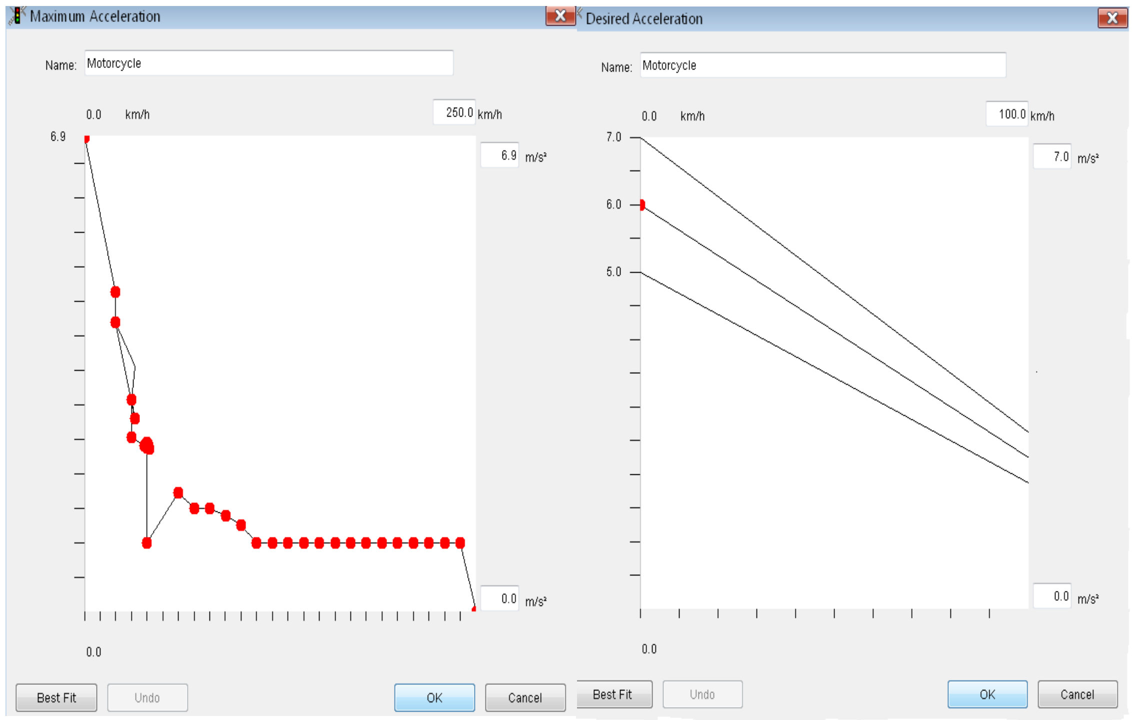


Figure 10.3 Maximum acceleration and desired deceleration of motorcycle in VISSIM

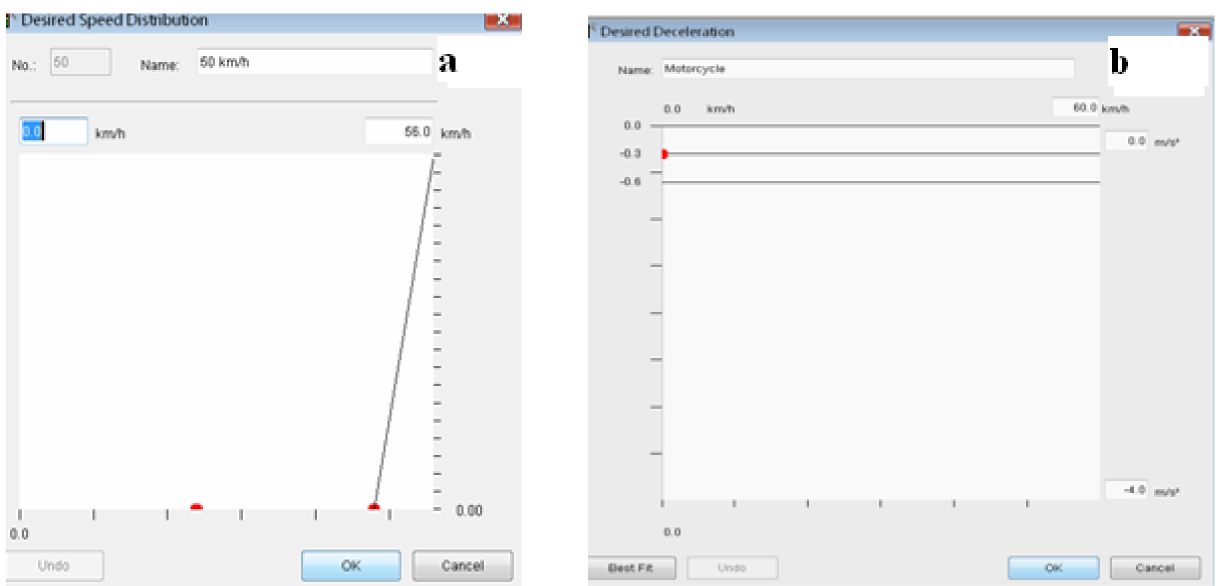


Figure 10.4 (a) Desired speed distribution (b) Desired deceleration of motorcycle

(b) Desired speed distribution

For any vehicle type, the speed distribution is an important parameter that has a significant influence on roadway capacity and achievable travel speeds. If not hindered by other vehicles, a driver will travel at his desired speed (with a small stochastic variation called oscillation). The more vehicles differ in their desired speed, the more platoons are created. If overtaking is possible, any vehicle with a higher desired speed than its current travel speed is checking for the opportunity to pass without endangering other vehicles, of course.

Stochastic distributions of desired speeds are defined for each vehicle type within each traffic composition. The window Desired Speed Distribution can be accessed via Base Data – Distributions – Desired Speed in the menu. A desired speed distribution can then be selected (single mouse click), edited (single mouse click and Edit or double click) or created (New). Creating or editing a desired speed distribution opens the window presented in Figure 10.4. The minimum and maximum values for the desired speed distribution are entered into the two fields above the graph (the left number must always be smaller than the right number). Intermediate points are displayed as red dots. They can be created with a single right button mouse click and moved by dragging with the left mouse button. Merging two intermediate points deletes the first one of them.

The horizontal axis depicts the desired speed while the vertical axis depicts the cumulative percentage from 0.0 and 1.0. Two intermediate points are generally adequate to define an s-shaped distribution, which is concentrated around the median value. Many other distributions, which have been imported into VISSIM, include weight, power, colour, and 3D model (for further information see VISSIM Manual 5.1, 2009).

(c) Driving behaviour parameters

The ‘Wiedemann’ approach includes (1) Vehicle Following Behaviour (2) Lane Change (3) Lateral Behaviour (4) Signal Control (for more detail see VISSIM Manual, 2009). This is also summarised in Table 10.1 These parameters can be attached to individual link types.

Each link and connector has a separate behaviour type and a display type, allowing independent handling of these attributes. It is still possible to change the behaviour or display of a group of links at once if all these have the same behaviour type respectively. The link behaviour type assigns one driving behaviour parameter set to any number of vehicle classes (and one default set). The link display type defines several display attributes for 2D and 3D. If an old network file is read, link types are split into link behaviour types and link display types and assigned to the respective links. Connectors get the same link behaviour type and display type as their origin links. In our study separate driver behaviour of motorcycle, links were created at intersection.

Table 10.1 Parameters involved in driving behaviour

Weidemann Approach	Major Parameters
Vehicle Following Behaviour	• Look ahead and look back distance – Minimum and Maximum • Temporary lack of attention • Average stand still distance • Additive and multiplicity part of safety distance
Lane Change	• Maximum deceleration • Deceleration -1 per second own and trailing • Accepted deceleration for own and trailing vehicle • Waiting time before defusion • Minimum headway • Safety distance reduction factor • Maximum deceleration and cooperative braking
Lateral Behaviour	• Desired position at free flow – Right, left and any • Observed vehicle on next lane –Diamond Shaping Queuing • Overtake on same lane • Vehicle class to be overtaken on left and right • Minimum lateral distance • Distance at 0 km and distance at 50 km
Signal Control	• Reaction to amber signal • Reduced safety distance close to stop line

(d) Dynamic traffic assignment

If the road network to be simulated becomes larger, it will normally provide several options to go from one point in the network to another and the vehicles must be distributed among these alternative routes. This problem of computing the distribution of the traffic in the road network for a given demand of trips from origins to destinations is called traffic assignment and is one of the basic steps in the transport planning process.

Traffic assignment is essentially a model of the route choice of the drivers or transport users in general. For such a model, it is necessary first to find a set of possible routes to choose from, then to assess the alternatives in some way and finally to describe how drivers decide based on that assessment. The modelling of this decision is a special case of what is called discrete choice modelling, and a lot of theory behind traffic assignment models originates from the discrete choice theory. The standard procedure in transportation planning is the so-called Static Assignment. In contrast to this, Dynamic Assignment procedure takes care of changes in travel demand during day and other time dependencies (such as changes in signal time during the day).

10.3 The study area

The test corridor is in the Air Quality Management Area (AQMA) in Edinburgh (Chapter 7). The links and connectors created in VISSIM for the test corridor are shown in Figure 10.5. The geometric details and traffic flow of some of the links along the test corridor are described in Table 10.2, which were observed from field study across the test section.

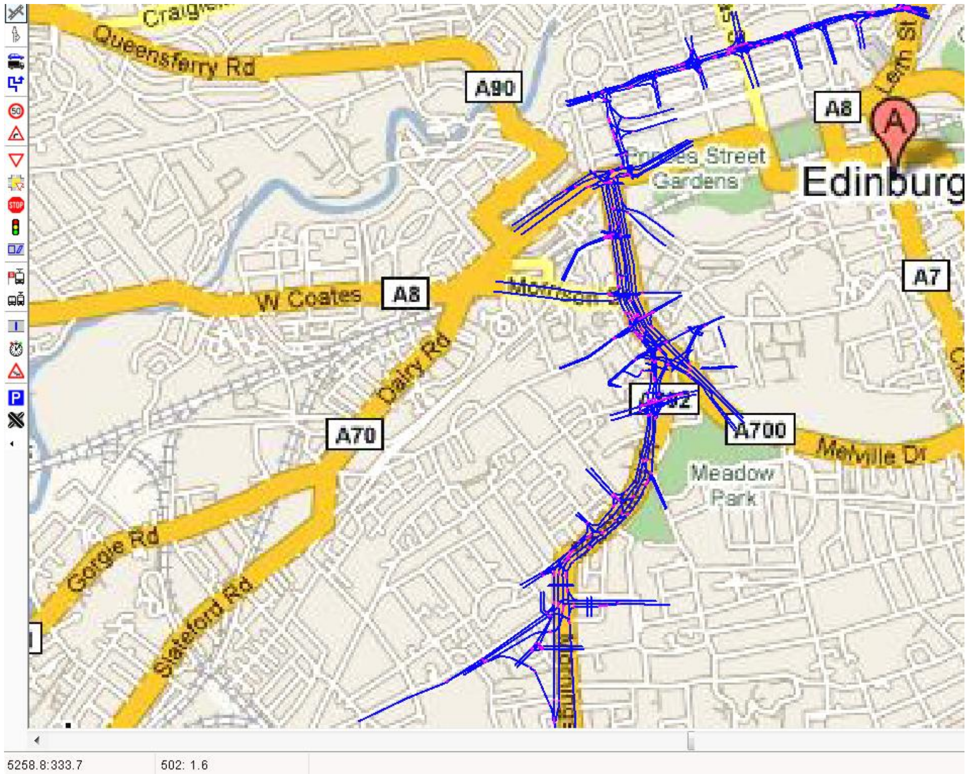


Figure 10.5 Test section created along AQMA area in micro-simulation

Table 10.2 General details of the test sections

Street name	Arm name	Total traffic AADT (15 hrs)	Number of motorcycles	% mix in total traffic	Average road width (m)
Queen Street	West Arm	11363	106	1	16
	East Arm	6527	63	1	
Princes Street	East Bound	15968	187	1	20
	West Bound	16430	164	1	
Toll cross	Home Street	13282	142	1	21
	Earl Grey Street	37373	720	1	
Home Street	North Bound	19422	173	1	14
	East Bound	15957	98	0	
Lothian Road	West Bound	17285	233	1	17
	East Bound	19053	158	0	

Total traffic volume ranged from 6527 to 37373 vehicles for a 15-hour count. That shows traffic variation ranged 5 times from one arm to other arms. It was found that motorcycles constituted only 1% of total traffic mix. The variation in road width observed in different sections of the test routes ranged from 14 to 21 meter. The detailed data collection along the street was done for different intersections and mid block using different methods. The details of different data collection methods are discussed below.

10.4 Data collection

Data were collected using a GPS system, video recording, speed gun and secondary sources. The traffic data, including signal data, were obtained by recording the traffic movements at each junction and junction approaches using a Fuji FinePix J10 digital camera housed in a compact chassis just 19 mm thick. The FinePix J10 incorporates an 8.2-Mega Pixel CCD sensor, a 2.5’’ LCD and a 3x Fujinon optical zoom lens that captures large groups or distant subjects with the ease of a 38mm-113mm equivalent. This made it possible to facilitate the conversion, compression, and backup of the video files during the data extracting process. The specification of the camera is detailed in Appendix 10.1.

Fifteen minute video footage intervals of traffic data and signal cycle was captured from 17:00 to 18:00 (British Summer Time) using the video camera from July 2008 to September 2008 on all the intersections along the test corridor. It was intentionally decided to record traffic during sunny afternoons and evenings as the pavement were dry, providing a good environment for obtaining high quality video images. The whole process for extracting data from the video footage was extremely time-consuming, including the time for data collection, video file conversion, trajectory extracting and data cleaning. If the density of the flow in the video were higher, more time would have been needed (Lee, 2008). After extracting the signal and traffic from the video footage, and some work of data processing of raw data, a database was finally built. The details of data collection period, time of data collection and name of the intersection are presented in Appendix 10.2. In addition to the collected data, traffic census data, signal controller details and other geometric details were collected from Edinburgh City Council; however, there are also some advantages of using the secondary source data as discussed in Chapter 5.

(a) Data processing

All the collected data requires processing to be used in the models. The data processing in this study was done in two stages. The first stage was the preliminary data processing, which was carried out soon after the recording was completed. During this stage, the basic signal parameters such as green, red, and amber times for each arm of the junction were calculated to constitute the database. The second stage was the advanced data processing for the input to VISSIM, which was needed as input file to run the model. This was undertaken before the start of simulation to analyse the interactions between and amongst vehicles such as following distances and speed differences. Details of driving behaviour characteristics, extracted signal time, traffic parameter, and other characteristics for developing motorcycle-driving cycle, from primary and secondary sources are given in the subsections below.

10.5 Modelling motorcycle driving characteristics in VISSIM

The geometric and traffic characteristics of the test corridor provided an environment to observe the interactions amongst vehicles, including filtering, queuing, discharging, merging, lane changing and stop and go behaviour. In addition, in such environments, vehicles (including motorcycles and other types of vehicles) had to interact not only with the vehicle ahead but also with the vehicles at lateral and oblique directions. Figure 10.6 a-c shows the manoeuvring of motorcycles into the available gaps at the intersection. This is a visual way to observe the driving characteristics in the traffic stream. From a data input point of view, there are many quantifiable parameters, which affect the simulation significantly as discussed below.

10.5.1 Traffic data

The typical example of the extracted and collected data at a test section from video recording technique is presented in Table 10.3. This traffic data was extracted for 15-minute durations. This was used for crosschecking the traffic flow from ECC classified traffic count data that were made available from ECC to input into the simulation model.

(a) Overtaking of motorcycle in traffic stream at Hanover Street

(b) Moving ahead of queue of motorcycle at Elder Street junction

(c) Filtering into traffic stream by motorcycle at Hanover Street

Figure 10.6 (a) Overtaking motorcycle (b) Moving ahead of queue (c) Filtering into traffic

Table 10.3 Composition of traffic data extracted from video

Name of Junction	Location : Bruntsfield					
Off Peak 15.45 pm	Car	LGV	Bus	Motorcycle	Cycle	Total
Towards Morningside	75	6	3	1	3	88
Opposite Morningside	73		1			74
Peak 5.00 pm						
Towards Morningside	85	7	3	1	3	100
Opposite Morningside	83	0	1	0	0	84

The detail of traffic summary, intersection phase and intergreen, stage sequence of the intersections along the corridor were also collected from ECC (detailed in Appendix 10.3).

10.5.2 Signal timings data

In addition, intersection phase data are required to design the signal. Intersection stage sequences with detailed arm nomenclature and inter-green phase data were collected from ECC along the routes of AQMA. The typical example of a 7-stage sequence for the Toll cross intersection is presented in Figure 10.7

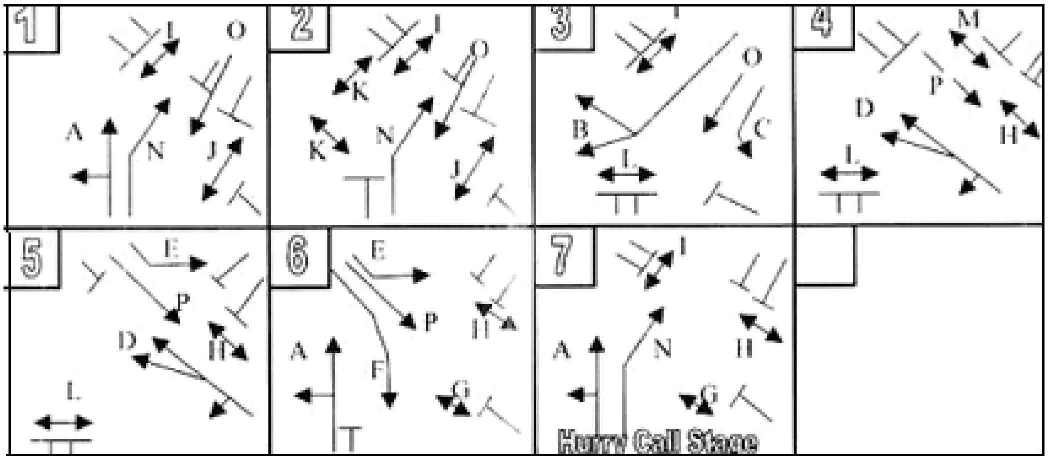


Figure 10.7 Toll Cross intersection - Stage sequence diagram

(a) Signal controller (SC)

In VISSIM, every signal controller junction (SCJ) is represented by its individual SC number and signal groups (also referred to as signal phase) as its smallest control unit. Depending on the selected control logic, VISSIM can simulate up to 125 signal groups per signal controller. VISSIM also discriminates between signal groups and signal heads. Details of cycle length and type of signal controller are presented in Table 10.4. A fixed-type signal controller was selected in our simulation study. It should be noted that ECC control the signal by the SCOOT system, so choosing fixed-type signal control is one of the assumptions in our study.

Table 10.4 Details of cycle length and type of signal controller

SCJ	Name	Type	Cycle time	Offset
2	'MBL'	Fixed Time	100.0	0.0

(b) Signal head

A signal head is the actual device, showing the picture of the associated signal group. Signal heads are coded in VISSIM for each travel lane individually at the location of the signal stop line. Vehicles wait approximately 0.5 m behind a signal head/stop line that displays red. Vehicles approaching an amber signal will proceed through the intersection if they cannot come to a safe stop in front of the stop line. Optionally, an advanced calculation method can be used for VISSIM to calculate a probability for whether the vehicle should continue through amber or not using three values of the driving behaviour parameters (see section on Driving Behaviour, VISSIM user manual, 2008).

Signal indications are typically updated at the end of each simulation second. If the controller module for VISSIM is equipped for switch times down to 0.1s, VISSIM is able to reflect this behaviour. However, this is dependent on the controller type. Signal head coding allows for the exact modelling of any kind of situation. This includes the ability to model different signal groups for different vehicle types on the same travel lane. For example, modelling a bus travelling in mixed traffic but yielding to its own separate signal phase is possible with VISSIM by selecting the appropriate vehicle classes for each signal head. Typical example of signal head built at different lane and different position are presented in Table 10.5.

Table 10.5 Detail of signal head at different lanes and positions in VISSIM

Signal Head	Name	Label	SCJ	Group	Position link	Lane	At	Vehicle_ Classes
234	‘‘MH_NS”	001	6	8	244	1	330.42	ALL
11	‘‘MH_SN”	002	6	8	210	1	63.81	ALL
9	‘‘MH_EW”	003	6	9	134	1	133.74	ALL
44	‘‘MH_WE”	004	6	11	341	1	4.94	ALL

Fixed time signal controls only Red end and Green end times that need to be defined along with timings for Amber and Red/Amber to run the signal controller. Both Amber as well as Red/Amber times can be set to 0 in order to switch them off. Also with fixed-time control, signal groups can be switched to green twice during one cycle. This is done simply by entering a second pair of switch times in the Red End 2 and Green End 2 fields (VISSIM Manual, 2009). Details about signal group and different time for Red End, Green End, Red Amber and Green Amber are presented in Table 10.6-10.8. These data were extracted from video file of the signal cycle at different intersections along the test corridor, which was obtained from the field recording.

Table 10.6 Details of arm name, green time and stages of Tollcross intersection

Date			Details of Arms	Max Green				Min	Ext
21/05/2003				A	B	C	D		
STAGE	1	A	Home St ahead and left	24				7	1
		N	Home St right turn	30				7	3
		O	Lauriston Pl ahead					7	
		I	Earl Grey St east Peds					7	
		J	Brougham St Peds					9	
	2	N	Home St right turn	20				7	3
		O	Lauriston Pl ahead					7	
		I	Earl Grey St east Peds					7	
		J	Brougham St Peds					8	
		K	Earl Grey + west TollX Peds					6	
	3	B	Lauriston Pl Right Turn	12				7	1
		C	Lauriston Place Left Turn	12				7	1
		O	Lauriston Place ahead					7	
		I	Earl Grey St east Peds					7	
		L	Home St west Peds					12	

Table 10.7 Details of arm name, green time and stages of Tollcross section-contd.

Date			Details of Arms	Maxm Green				Min	Ext
21/05/2003				A	B	C	D		
Stage	4	D	Brougham St	8				8	1
		P	Earl Grey St ahead arrow					4	
		H	Lauriston Pl Peds					6	
		L	Home St west Peds					12	
		M	Lauriston Pl north Ped					7	
	5	D	Brougham Street	8				8	1
		E	Earl Grey St ahead left	16				7	1
		P	Earl Grey St ahead arrow					4	
		H	Lauriston Pl south Peds					6	
		L	Home St west Peds	24				12	1
	6	A	Home St ahead and left	24				7	1
		E	Earl Grey St ahead arrow	16				7	1
		F	Earl Grey St right turn	16				7	1
		P	Early Grey St ahead arrow					4	
		G	Home St east Peds					6	
		H	Lauriston Pl south Peds					6	
	7	A	Home St ahead and left	24				7	1
		N	Home St right turn	20				7	3
		G	Home St east Peds					6	
		H	Lauriston Pl south Peds					6	
		I	Early Grey St east Peds					7	

Table 10.8 Signal group and different time for Red End, Green End & Red Amber

Signal group	Name of Junction (Code)	SCJ	Red End	Green End	Time in red amber	Time in amber
21	'MBL-NS'	2	0.1	55.0	3.0	2.0
9	'ELD_QST-WE	6	0.1	84.0	2.0	2.0
10	ELD_QST-ES	6	0.1	84.0	2.0	2.0
11	ELD_QST-WS'	6	84.0	97.0	2.0	2.0
12	ELD-QST-SE	6	84.0	97.0	2.0	2.0

(c) Inter-green period of a phase

The inter-green period of a phase consists of both the yellow (amber) indication and the all-red indication (if applicable). This phase is governed by three separate concepts: stopping distance, intersection clearance time, and pedestrian crossing time, if there are no pedestrian signals, as shown in Figure 10.8. The yellow signal indication serves as a warning to drivers that another phase will soon be receiving the right-of-way. The inter-green interval, therefore, should be long enough to allow vehicles that are greater than the stopping distance away from the stop-bar to brake easily to a stop. The inter-green interval should also allow vehicles that are already beyond the point-of-no-return to continue through the intersection safely (VISSIM Manual, 2008). In our study, the inter-green period was obtained from ECC and used as input to VISSIM. The example of inter-green phase of the Toll cross section is presented in Table 10.9.

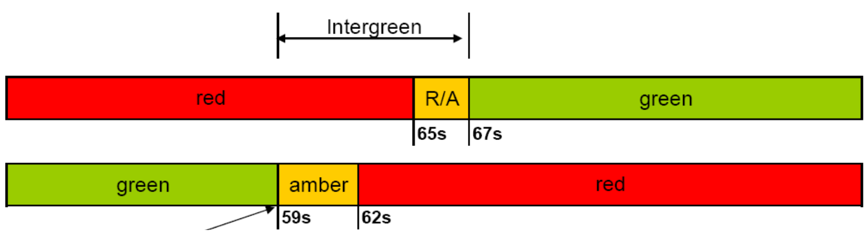


Figure 10.8 Inter-green period of cycle length 105 seconds

(Source: DBM modelling guideline, 2006)

Table 10.9 Inter-green Phase

	To Phase																
From phase		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	A		5		5							7	5				
	B	5			5	5	5					8		5	5		5
	C					5			5		5				5		5
	D	7	5				5	5			5	9			5	5	
	E		5	7						5	8			6	5	7	
	F		5		5					5			7		5		
	G				5											5	
	H			5												5	
	I					6	6										6
	J			8	8	5											5
	K	5	5		5												
	L	8					5								8		
	M		6			5									5		
	N		6	8	5	5	5						5	8			5
	O				5	5		7	5								5
	P		5	5						5	5				5	5	

10.5.3 Parking lots in VISSIM

To define travel demand using an origin-destination matrix (O-D Matrix) the area to be simulated is divided in sub-areas called zones and the matrix contains the number of trips that are made from all zones to all zones for a given time interval. Thus, the dimension of the matrix is: (number of zones) x (number of zones).

In contrast to O-D matrices, a trip chain file supplies the simulation with more detailed travel plans for individual vehicles; however, the coding effort is much higher (see Chapter 8). To model the points where the vehicles actually appear or leave the road network, a network element ‘parking lot’ is used. A parking lot belongs to a certain planning zone, i.e. trips originating from this zone or ending in this zone can start or end at this parking lot. A zone can have more than one parking lot. In that case, the coming or going traffic can use any of the parking lots belonging to a certain zone. The total originating traffic of a zone is distributed to its parking lots according to user-defined relative flows. One parking lot can belong to one zone only; however, the vehicle movement in the street can be connecting the zone to zones on a different network.

In order to reduce the complexity of a the network and thus to reduce computing time and storage for paths, it is sensible to define some parts of the VISSIM network as nodes, i.e. those parts of a network where paths could diverge. In general, these nodes are treated equivalent to what is normally described in the real world as a ‘junction’.

To derive the driving cycle of a motorcycle on test routes, the parking lot concept/method was used to model driving cycles along a test corridor. This was implemented by entering motorcycles at the origin (Morningside– Holy Corner junction) called Zone 1 and leaving the test track at York Place/Elder Street (Zone 2) of the corridor. A total of 25 nodes (junction along the test corridor) were created between the two zones (1 and 2) to converge path along corridor from origin to destination zone of the motorcycle test run (See Figure 10.9). In VISSIM, a vehicle class and speed can be assigned for each vehicle in the parking lot. Also, separate desired speeds were assigned from 0 to 80 km h^{-1}, taking account of the maximum speed in urban driving of motorcycles in Edinburgh in real world scenarios (see Chapter 6).

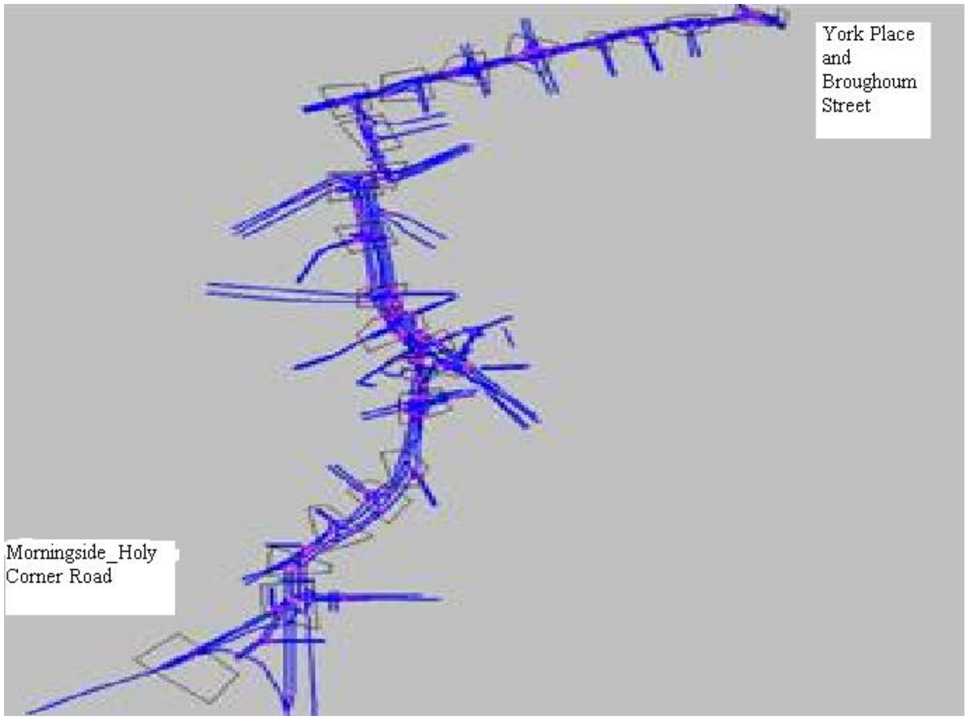


Figure 10.9 Creation of nodes for assignment of vehicles from one end to another

(a) Trip chain files

It should be noted that in our study test corridor was defined in the city centre and motorcycles were assigned to enter from the origin of the test section to the destination of the test section. The trip chain file allows supplying the simulation with more detailed travel plans for individual vehicles; however, the coding effort is much higher.

In our study trip chain for test corridor started from Morningside–Holy Corner junction to York Place Brougham Street (see Figure 10.9).

In the absence of an O-D matrix for the study area and the limited application of simulation (i.e. just to obtain the driving cycle) a trip chain file was created. A trip chain is associated with a vehicle and identified by three numbers:

- Vehicle number
- Vehicle type
- Origin zone number

After this ‘header’ one or more trips follow. A trip is defined by a group of four numbers:

- Departure time
- Destination zone number
- Activity number
- Minimum stay time

The departure time of the next trip depends on the arrival time in that zone and on the minimum stay period for this activity. The specified departure time for the next trip will be taken in to account only if the minimum stay time is guaranteed. If a vehicle arrives too late, the departure time is corrected to the sum of the actual arrival time plus the minimum stay time. The typical example of a trip chain file for our simulation study for motorcycle is presented in Table 10.10. Code value 400 were assigned for motorcycles and three sets of departure times were set up (100, 600, and 1100 sec).

Table 10.10 Vehicle number, type and its trips characteristics

Vehicle number	Vehicle Type	Origin zone number	Departure time	Destination zone number	Activity number	Minimum stay time
100	400	1	100	2	101	50
600	400	1	600	2	101	50
1100	400	1	1100	2	101	200

10.6 Development of driving cycle of motorcycle in VISSIM

The local driving cycle requires speed-time sequence on the particular street. To test the feasibility of the application for the motorcycle driving cycle the Gorgie Road section was selected as a pilot study due to the higher proportion of two-wheelers and bikes on this section. Traffic data from Edinburgh City Council were assigned to a road, the signal time was measured by using a stopwatch at the railway bridge crossing at Gorgie Road and Robertson Avenue and the Ardmillan Terrace crossing. The road network of 0.75 km length, signal timing, and traffic composition was supplied for the input for micro-simulation study in VISSIM 4.20. The simulation was run with five different seed numbers (35, 42, 60, 70 and 85) with simulation resolution of 10 sec/simulation and with a controller frequency of one pass per simulation seconds. The results obtained were not sound and applicable because the simulated model was neither calibrated nor validated, but they were used for training purpose (Kumar et al., 2007). VISSIM 4.20 module has the limitation of network of 1500 m and no dynamic assignment module for traffic assignment was available. Therefore the advanced version of VISSIM 5.10, which has a Dynamic Assignment module and network can be created up to 10 km length was used for the application of micro-simulation in AQMA of longer length of 4.1km (For detailed data analysis and results refer Chapter 11).

10.6.1 Driving cycle simulation study of motorcycles in Edinburgh for AQMA area of Edinburgh City Council.

The creation of a highly detailed video-captured database containing information on the signal time and traffic flow for 21 intersections along a section of the AQMA area in Edinburgh was good a base for developing the driving cycle. The video was recorded near a traffic signal so the interactions between vehicles could be observed. A computer programme was developed to extract Red End and Green End time and numbers of the vehicles passing through that arm using video images. The database built by this programme also included the types, widths and lengths of the vehicles. From this database, a wide range of relevant traffic parameters such as driving behaviour parameters, simulation parameters etc. were generated for further analyses and model calibrations.

10.6.2 Driving behaviour parameters in VISSIM

These parameters are available in the VISSIM model, which affect the driving cycle (See Table 10.1 and Table 10.11 for details). The different parameters are described below:

Look ahead distance — The Look ahead defines the distance that a vehicle can see forward in order to react to other vehicles either in front or to the side of it (within the same link). This parameter is in addition to the number of Observed Vehicles.

Maximum value — The maximum value is the maximum distance allowed for looking ahead. It needs to be extended only on rare occasions (e.g. for modelling railways if signals and stations are to be recognized in time).

Minimum value — The minimum value is important when modelling lateral vehicle behaviour, especially if several vehicles can queue next to each other (e.g. bikes) as this value needs to be increased. The value depends on the approach speed. In urban areas, it could be 20-30 m (60-100 ft).

Minimum look ahead distance — without increasing the minimum look ahead distance while modelling lateral behaviour it may happen that vehicles will not stop for red lights or for each other. The number of observed vehicles should not be changed to compensate for this behaviour as it might easily result in unrealistic behaviour elsewhere.

Observed vehicles — The numbers of observed vehicles affects how well vehicles in the network can predict other vehicles' movements and react accordingly. As some of the network elements are internally modelled as vehicles, it might be useful to increase this value if there are several cross sections of network elements within a short distance. However, the simulation will run slower with higher values.

Look back distance — The Look back distance defines the distance that a vehicle can see backwards in order to react to other vehicles behind (within the same link).

Maximum value — The maximum value is the maximum distance allowed for looking backward. In networks with many small meshes, e.g. with many connectors over a short distance, the simulation speed can be improved if the maximum look back distance is reduced from the default value.

Minimum value: The minimum value for look back distance is same as look ahead distance.

Temporary lack of attention (‘sleep’ parameter) — Vehicles will not react to a preceding vehicle (except for emergency braking) for a certain amount of time.

- Duration defines how long this lack of attention lasts.
- Probability defines how often this lack of attention occurs.

The higher both of these parameters are, the lower the capacity on the corresponding links will be: the car-following model selects the basic model for the vehicle following. The Wiedemann 74 model is mainly suitable for urban traffic and was therefore selected for car following in our study. The following changes were made in this parameter to get the desired value of speed in the real world of the motorcycle, which is presented, in Table 10.11. Once these changes were made then the simulation model was run with 1-second simulation resolution and with different random seeds as described below.

Table 10.11 Comparison of simulation driving behaviour parameters for urban and motorcycle lane

Driving behaviour	Simulation parameters	Range	Urban lane	Motorcycle lane	Reason
Car-following	Look ahead distance (m)	Maximum value	0	5	Required more distance because of less height and less sight distance
		Minimum value	250	250	
	Observed vehicle		4	2	Due to con-strained sight ahead
	Look back distance (m)	Maximum value	0	0	
		Minimum value	150	150	
	Temporary lack of attention (sec)		0	0	
Necessary lane changes	Maximum deceleration m/sec^2	Trailing vehicle	-3	-3	
		Own	-2	-3	
	-1m/sec^2/distance	Trailing	10	25	
		Own	10	25	
	Accepted deceleration (m/sec^2)	Own	-1	-1	
		Trailing	-1	-1	
	Waiting time before diffusion		120	60	Gipps (1990)
	Maximum deceleration for cooperative braking		-2	-3	It has more power/mass ratio to control
Lateral	Desired position of free flow		Middle of lane	Any	
	Overtaking on same lane		Not allowed	Yes both on left and right	
	Minimum lateral distance	Distance (m) at 0 km h^{-1}	1	0.5	It need less space to filter into traffic
		Distance (m) at 50 km h^{-1}	1	1	
Signal control			Default	Default	

10.6.3 Simulation parameters

(a) Simulation resolution

The number of times the vehicle's position is calculated within one simulated second range from 1 to 10. The input of 1 results in the vehicle moving once per simulation second. An input of 10 results in the vehicle's position being calculated 10 times per simulation second, thus making vehicles move more smoothly. The change of simulation speed is inversely proportional to the number of time steps. For the study, one-second simulation resolution was selected because this was required unit for input to the development of driving cycle.

(b) Random seed

This parameter initializes the random number generator. The simulation runs with identical input files and random seeds generate identical results. Using a different random seed changes the profile of the traffic arriving (stochastic variation of input flow arrival times) and therefore results may change.

Figure 10.10 shows the simulation parameter and number of runs for the development of the motorcycle driving cycle. Other simulation parameters include start time and start date.

Table 10.12 shows characteristics of four time simulations runs made to observe the different speed for a period of 3600 s in calibration process.

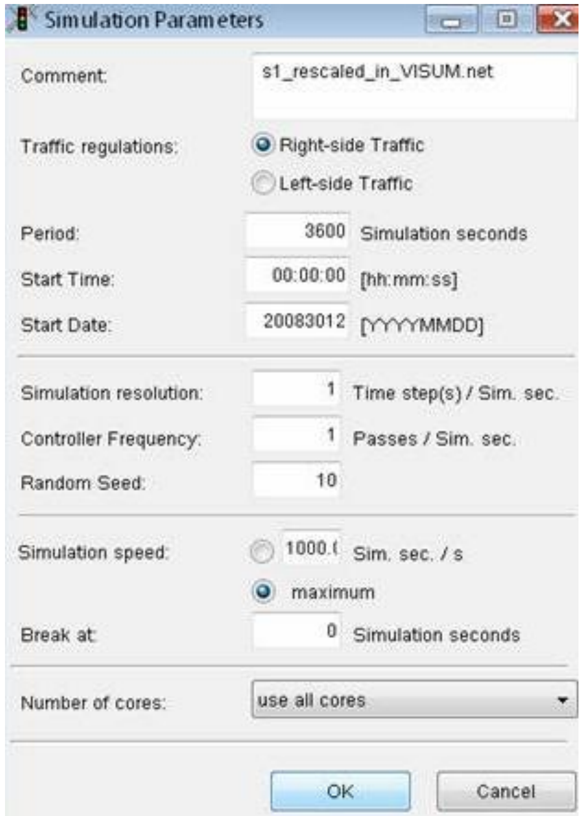


Figure 10.10 An example of simulation process of driving cycle (for random seed 10)

Table 10.12 Characteristics of the test runs for simulation

Period (seconds)	Simulation Resolution	Controller Frequency	Random Seeds	Simulation Speed
3600	1	1	10	Maximum
3600	1	1	30	Maximum
3600	1	1	90	Maximum
3600	1	1	50	Maximum

10.7 Model calibration and validation

Microscopic simulation models are becoming increasingly important tools in modelling transport systems. A large number of models are used in many countries. The most difficult stage in the development of such models is calibration and validation (Brockfed et al., 2004). Calibration is a process of adjusting and determining a set of parameters in a model by using observed data. Its purpose is to facilitate the accuracy of the model outputs. In this section, the calibration process is carried out based on the available results from the simulation study.

10.7.1 Microscopic calibration of the traffic flow model

Most model parameters influence the longitudinal dynamics of single vehicles. Calibration of these parameters requires measurements on the level of single vehicles, i.e. data about headways, perception thresholds and driver characteristics have to be available. In addition to the car-following model parameters, the selected time step is important for the quality of the simulation. Smaller time steps allow a more realistic modelling of acceleration and are useful in a microscopic emission model.

In our study, simulation resolution was kept one second to create the smooth driving pattern (refer to Figure 10.10). Obviously, the modelling quality of the one-second simulation is higher, since in the one-second case some unrealistic peaks can be seen which results from the over-reaction. However, for most applications, the quality would be sufficient. Otherwise, the time step can be reduced to give more realistic results, but that requires a proportionally increased computing time.

The value of random seeds was changed from 10 to 90 to see stochastic variation of input vehicles hence the results were different. Vehicle code (400) was assigned for the motorcycle. The vehicle coding helped to keep the segregated record for the motorcycle. Vehicle record evaluation file was selected in VISSIM for output. The 2.fzp file was created after the simulation run (a sample of the output file is presented in Appendix 10.4). This provides the speed and acceleration data of the motorcycle along the test corridor at one second intervals (analysis of the data is presented in Chapter 11). Figure 10.11 presents how the VISSIM model is able to reproduce the real-world speed time sequence of the motorcycle driving cycle: the x-axis shows time and the y-axis shows the speed of motorcycles along the test corridor.

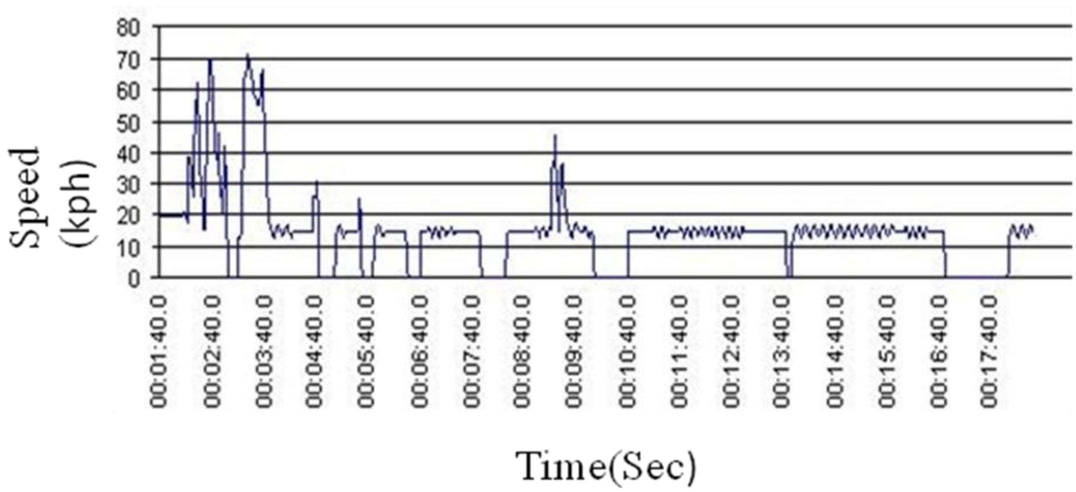


Figure 10.11 Simulated driving cycle of motorcycle

10.7.2 Measuring goodness of fit through the GEH statistic

At the heart of any calibration technique is the comparison between simulation outputs and observed measurements of various traffic measures. The review of measures of fit used by Hollander and Liu, 2008 shows that the different measures used during calibration process do not use any uniform scale or consistent criteria to indicate well fit. The GEH technique was developed by Barcelo and Casas (2004) and used by Chu et al. (2004) and Oketch & Carrick (2005). The Directorate of Traffic Operations (DTO) in the UK also adopts this technique for calibration of micro simulation models. This technique was applied to a single pair of observed-simulated measurement. A GEH result of < 5 indicates a good fit.

The GEH statistic is a standard measure of the 'goodness of fit' between observed and modelled flow. For our case, speed characteristic of the corridor is selected to represent the driving cycle. Therefore, instead of flow, observed speed in different class interval has been used for calibration and validation process. The GEH is calculated as follows in Equation 10.1:

$$\sqrt{\frac{(M-C)^2}{(M+C)/2}}$$

---------------------Equation 10.1

Where M and C are the modelled and observed speed respectively.

Smaller GEH values indicate a better 'fit' between observed and modelled speed. As a guide, modellers should aim for GEH values of less than 5 (DTO Modelling Guidelines Version 2.0, 2006).Tables 10.13 and 10.14 shows the GEH values for the calibration and validation process respectively. In this study, two sets of real world data have been used. C_1 data set is used for the calibration process, while C_2 is used for the validation process. These validation and calibration data sets were obtained by conducting real-world driving along the test section. Speed was categorised into seven categories. Their frequency was observed from both real world and simulated conditions. M shows the percentage of model frequency and C shows the percentage of observed frequency for speed ranges between 0-60 km h^{-1} The GEH statistics were applied on the results of test routes.

Table 10.13 GEH value for calibration process

Random Seeds	Speed km h^{-1}	Frequency (Fi)	Modelled (M)	Observed (C_1)	$(M-C_1)$^2	$[M+C_1]/2$		GEH= $\sqrt{\frac{(M-C_1)^2}{(M+C_1)/2}}$
90	0	208	20.59	1.76	354.54	11.18	5.63	
90	10	19	1.88	34.71	1077.46	18.29	7.67	
90	20	672	66.53	12.65	2903.87	39.59	8.56	
90	30	29	2.87	14.26	129.81	8.57	3.89	
90	40	21	2.08	19.41	300.42	10.75	5.29	
90	50	15	1.49	15.15	186.65	8.32	4.74	
90	>60	35	3.47	2.06	1.98	2.76	0.85	
	Sum total	999		C_1	Average GEH Value		5.23	Rejected
30	0	212	16.91	1.76	229.26	9.34	4.96	
30	10	40	3.19	34.71	993.26	18.95	7.24	
30	20	970	77.35	12.65	4186.79	45.00	9.65	
30	30	26	2.07	14.26	148.63	8.17	4.27	
30	40	3	0.24	19.41	367.59	9.83	6.12	
30	50	2	0.16	15.15	224.63	7.65	5.42	
30	>60	1	0.08	2.06	3.92	1.07	1.91	
	Sum total	1254		C_1	Average GEH Value		5.65	Rejected
50	0	194	15.47	1.76	187.85	8.62	4.67	
50	10	28	2.23	34.71	1054.50	18.47	7.56	
50	20	823	65.63	12.65	2807.19	39.14	8.47	
50	30	83	6.62	14.26	58.46	10.44	2.37	
50	40	5	0.40	19.41	361.50	9.91	6.04	
50	50	2	0.16	15.15	224.63	7.65	5.42	
50	>60	1	0.08	2.06	3.92	1.07	1.91	
	Sum total	1136		C_1	Average GEH Value		5.20	Rejected
10	0	193	15.39	1.76	185.67	8.58	4.65	
10	10	20	1.59	34.71	1096.34	18.15	7.77	
10	20	697	55.58	12.65	1843.42	34.11	7.35	
10	30	30	2.39	14.26	140.95	8.33	4.11	
10	40	23	1.83	19.41	308.97	10.62	5.39	
10	50	12	0.96	15.15	201.36	8.05	5.00	
10	>60	35	2.79	2.06	0.54	2.42	0.47	
	Sum total	1010			Average GEH Value		4.96	**Selected**

10.7.3 Validation of model

The stochastic nature of micro-simulation creates an excellent opportunity for examining their variation. The validation stage is meant to confirm the predictive power of the calibrated model using an independent set of data. There are different validation methods, such as visual validation (Toledo and Koiutsopolos, 2003; Park and Qi, 2005; Oketch and Carrick, 2005); validation using measure of fit; statistical validation by arranging the simulated and observed measurement as two time series, then comparing these two series; statistical validation using two sample tests (Barcelo and Casas, 2004; Park and Qi, 2005) and indirect statistical validation by testing whether some product of simulation outputs resembles the respective product of the field data.

In contrast to calibration, in the validation stage most researchers use more statistically rigorous tests, which state a well-defined level of confidence. Validation is neither more nor less rigorous than the calibration process, it is important to ensure that the validation test doesn’t simply repeat what has already been tested in the calibration process. Therefore, two sets of data has been utilised, one for calibration and the other for validation, as presented in Table 10.13 and Table 10.14.

Four values of random seeds have been used in the calibration and validation of the model (these are the four random seeds which showed the best results that are closest to the real world driving cycle in the initial model runs). These four random seeds where then statistically investigated using the GEH statistical goodness of fit (DTO Modelling Guidelines Version 2.0, 2006).

The collected real world data were randomly assigned to two data sets; one for calibration of the model and for the validation. Table 10.13 and 10.14 show the results obtained from the calibration and validation processes. In both cases it seems that the only random seed value which produces statistically significant results (GEH value <5) is random seed No. 10. Therefore, this random seed was selected for the development of the driving cycle into VISSIM. Once the driving cycle result was validated then it was integrated with the NAEI database. This integrated NAEI database provides the modal estimates of emission during different driving modes. Details of the resulting emission estimations are discussed in Chapter 12.

Table 10.14 GEH value for validation process

Random Seeds	Speed (km h^{-1})	Frequency (Fi)	Modelled (M)	Observed (C_2)	$(M-C_2)$^2	$[M+C_2]/2$		GEH= $\sqrt{\frac{(M \; -C2)^2}{(M+C_2)/2}}$
90	0	208	20.59	2.27	335.91	11.43	5.42	
90	10	19	1.88	34.42	1058.73	18.15	7.64	
90	20	683	67.62	12.32	3058.18	39.97	8.75	
90	30	29	2.87	18.27	237.18	10.57	4.74	
90	40	21	2.08	18.56	271.46	10.32	5.13	
90	50	15	1.49	11.33	96.95	6.41	3.89	
90	>60	35	3.47	2.83	0.40	3.15	0.36	Rejected
	Sum total	1010		C_2	Average GEH Value		5.13	
30	0	212	16.91	2.27	214.32	9.59	4.73	
30	10	40	3.19	34.42	975.28	18.80	7.20	
30	20	959	77.35	12.32	4228.84	44.84	9.71	
30	30	26	2.07	18.27	262.39	10.17	5.08	
30	40	3	0.24	18.56	335.48	9.40	5.97	
30	50	2	0.16	11.33	124.81	5.75	4.66	
	>60	1	0.08	2.83	7.58	1.46	2.28	Rejected
	Sum total	1243		C_2	Average GEH Value		5.66	
50	0	194	15.47	2.27	174.35	8.87	4.43	
50	10	28	2.23	34.42	1035.97	18.33	7.52	
50	20	823	65.63	12.32	2841.64	38.98	8.54	
50	30	83	6.62	18.27	135.80	12.45	3.30	
50	40	5	0.40	18.56	329.66	9.48	5.90	
50	50	2	0.16	11.33	124.81	5.75	4.66	
50	>60	1	0.08	2.83	7.58	1.46	2.28	Rejected
	Sum total	1136		C_2	Average GEH Value		5.23	
10	0	193	15.39	2.27	172.25	8.83	4.42	
10	10	20	1.59	34.42	1077.44	18.01	7.74	
10	20	687	55.58	12.32	1871.36	33.95	7.42	
10	30	30	2.39	18.27	252.16	10.33	4.94	
10	40	23	1.83	18.56	279.60	10.19	5.24	
10	50	12	0.96	11.33	107.63	6.14	4.19	
10	>60	35	2.79	2.83	0.00	2.81	0.02	**Selected**
	Sum total	1000		C_2	Average GEH Value		4.85	

10.8 Summary

A traffic micro-simulation model has been used in assessing the traffic performance of highway and street systems, transit, and pedestrians and other expanded application in transportation engineering and planning practice (Dowling, 2003.).

To obtain the driving cycle the VISSIM traffic simulation model is used because other types of models are often imperfect versions of actual traffic behaviour due to their limited modelling of actual driver behaviour. VISSIM is micro-simulation software that is being used by different regions to analyse multi-interaction of transportation systems.

The longitudinal and lateral movement of motorcycles are covered in car-following and the lateral parameters of driver behaviour in VISSIM. Other factors like lane change, signal control and external influences affect the motorcycles movement models.

To model these movements base data of vehicle acceleration, speed distribution, weight distribution, power distribution, vehicle class and category, driver behaviour data and trip chain files are the major input parameters. However, processing of data is difficult and will have implications on the results. Some data such as traffic flow, signal time and intersection phase data have been collected with video recording techniques or from secondary sources such as Edinburgh City Council. The motorcycle driving cycle was derived by creating the ‘parking lots’, which allows motorcycles to arrive from origins to destinations.

The models were run with five different seeds to calibrate the result of the driving cycle of the motorcycle. The calibration and validation of the model were accepted at a GEH below 5. Finally, these derived driving cycle data sets were integrated with the NAEI database to estimate the emissions. The data analysis and emission results of the data are explained in Chapters 11 and 12.

CHAPTER 11 DATA ANALYSIS MICRO-SIMULATION RESULTS

11.1 General

Development of driving cycles and estimation of emissions from micro-simulation models can be performed on a number of different levels, from individual vehicle emission estimation to citywide emission estimation (Lesort et al., 1996; TSai, 2003; Chen, 2003; Andre, 2009). The level of details selected for the emission estimation model should correspond to the vehicle that is being modelled (Sturm et al., 1997). The analysis presented in this chapter considers the potential use of driving cycle data from micro-simulation studies to provide realistic inputs to a vehicle emissions model capable of operating in real-time along an AQMA in Edinburgh. Then, the application of TRL emission coefficients from NAEI UK database as input to the vehicle emission model is presented, and finally comparisons of the driving cycle using micro-simulation and real-world driving cycle are presented. This chapter deals with the results and implications for estimating CO, HC and NO_X emissions from driving modes obtained from the simulation approach.

11.2 Developing the micro-simulation model along AQMA test route in Edinburgh city centre

The methodological aspect of developing the micro-simulation model has been discussed in Chapter 10 (Section 10.7).

11.2.1 Characteristic of signal cycle

Signal cycle length is composed of the total signal time to serve all of the signal phases including the green time plus any change in interval. Longer cycles will accommodate more vehicles per hour but that will also produce higher average delays. The cycle length includes the green time plus the vehicle signal change interval for each phase, totalled to include all signal phases. The best cycle length is the one that provides for a minimum amount of delay at each intersection but also provides for adequate progression along the corridor. The minimum delay cycle length produces the overall minimum delay for each approach to the signal. In our study area, cycle length and signal phase were controlled by the SCOOT system; this system is based on traffic loading, therefore removing dependency on signal plans, which have to be expensively updated[1].

Nevertheless, data collected in this study from field does not show much variation in signal cycle length. The detail of cycle length is given in Table 11.1. Two junctions of the test corridors were located at the extreme north east end of the test network (a) Elder Street–Queen Street and south west end (b) Morningside- Holy Corner intersection. York Place–Brougham Street intersection has a signal cycle length of greater than 120 sec; however, the signal cycle length was found to be lowest (80 seconds) on the extreme south side for Bruntsfield-Home Street intersection of test corridor. Signal cycle length was 100 sec between the extreme north and south ends for most of the intersection. It indicates that traffic flow at the outer periphery of the city centre for example Queen Street is higher than lower one (Bruntsfields, Travit Street intersection). Therefore requires more signal cycle length. It is also clear that especially in the centre area of the test corridor, traffic flow is higher.

Table 11.1 Signal cycle length across the test sections

Signal Name	Cycle length (second)
Bruntsfield-Home Street	80
Tarvit Street, East – West	80
York Place – Brougham Street	120
Elder Street – Queen Street	120
Shandwick Place –Lothian Road	100
Western Approach Road	100
Fountainbridge, East – West	100
Frederick Street – Queen Street	100
Gilmore Park	100
Toll Cross	100
New Castle Street – Queen Street	100
Hanover Street – Queen Street	100

11.2.2 Observation of motorcycle driving speed in different random seeds

1 (www.http://www.scoottc.com/WhatIsSCOOT.php?menu=Overview).

Models with the same number of random seeds and input files have the same result, but the random seeds with different input files will have different result and vice versa. The random seed affects the realization of the stochastic quantities in VISSIM, such as inlet flows and vehicle capabilities (VISSIM Manual, 2008). Simulation runs were made with different random seeds. The corresponding frequency of speeds was estimated with the change of random seeds (90, 30, 50, and 10). The result shows that most of the time, speed were in the range of 10-30 km h^{-1} and 0-10 km h^{-1}, higher frequencies than the real-world driving, where it was found to be concentrated in the range of 0-20 km h^{-1} and 30-69 km h^{-1} (Figure 11.1).

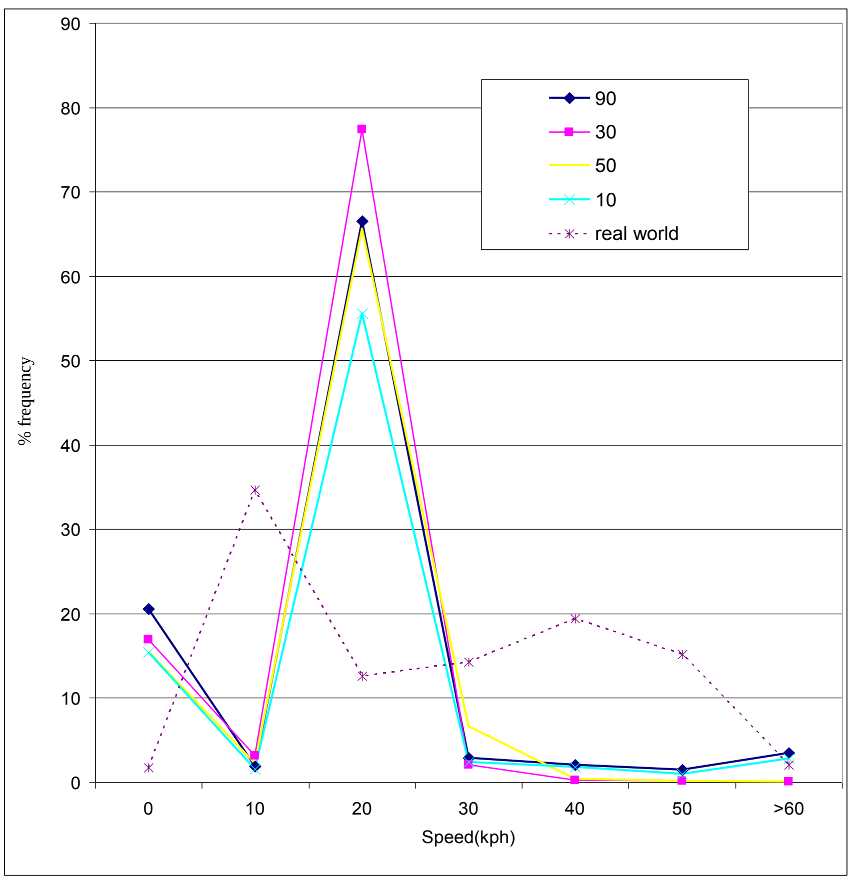


Figure 11.1 Variations in speed with random seeds.

This also shows the deviation between real world and micro simulation approach. The the model output, its relevance and integration with NAEI database are discussed further.

11.2.3 Model outputs

For every simulation run, output files are generated during according to the definition and configuration specific to each evaluation type. The evaluation type may include link evaluation, vehicle record, travel time and signal plan according to user requirements (VISSIM Manual, 2008). For deriving the driving cycle, the vehicle record was the most significant evaluation aspect; therefore, the vehicle record is evaluated as an output result. Model outputs from VISSIM were automatically written and stored in output files. The output file *2.fzp* (see Appendix 10.4) recorded each vehicle's actions during each simulation run time interval. For each individual vehicle, the model provided the following instantaneous speed data at intervals of 1 second or 0.1 second along the test corridor. The characteristics of this simulated driving cycle were evaluated based on similar assessment criteria of EMDC (Chapter 7).

11.2.4 Characteristic of the derived simulated driving cycle (DC)

Table 11.2 shows the characteristics of the simulated driving patterns along the AQMA corridor in Edinburgh. A large proportion of the cycle time was spent in cruising, while time spent in idling proportion was less. The average cycle speed over the whole driving cycle (V_1) was 14.4 km h^{-1}, while the average running speed (V_2) was 18.22 km h$^{-1.}$ Average acceleration was 0.65 m s^{-2}, while average deceleration was 0.556 m s^{-2}. The mean length of driving period was 1010 second (around 16 minutes). Total driving length was 4.084 km (4.1 km). Figure 11.2 shows the typical simulated driving cycle for motorcycle in AQMA.

Table 11.2 Comparison of driving characteristics of simulated driving cycle and EMDC

Assessment parameter	Value from Simulated DC	Value from EMDC
Average deceleration of all deceleration phases (m s^{-2}) (d)	0.55	2.59
Average acceleration of all acceleration phases (m s^{-2}) (a)	0.65	1.28
Average speed of the entire driving cycle (km h^{-1}) (V_1)	14.55	33.50
Average running speed (km h^{-1}) (V_2)	18.22	38.85
Mean length of driving period C (sec) (C)	1010.00	769.63
Time proportion of driving modes in idling (fraction of time spent at speed of 0-3 km h^{-1} (P_i) %	18.31	1.51
Time proportion of driving modes in acceleration (a >0.1 m s^{-2}) (P_a) %	24.05	44.45
Time proportion of driving modes in deceleration modes (d <0.1 m s^{-2}) (P_d) %	28.61	46.87
Time proportion of driving modes in cruising modes (a <=0.1 ms^{-2}, d <=0.1 m s^{-2}) (P_c) %	29.40	7.24
Average number of acceleration and deceleration changes within one driving period (M)	58.00	1251
Root mean square acceleration (RMS)	0.73	7.83
Positive kinetic energy (m s^{-2}) (PKE)	44.20	2.81
Total driving length (m) (L)	4084.00	7313.59

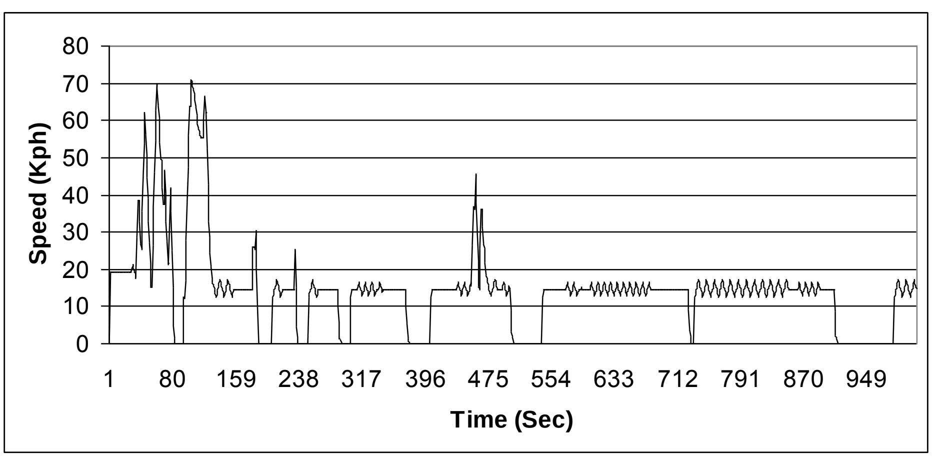


Figure 11.2 Simulated driving cycle of motorcycle for Edinburgh AQMA test routes

11.2.5 Comparison of characteristics of simulated and EMDC urban driving cycles

The EMDC and other international driving cycles were developed based on real-world data collection. Very few simulated driving cycles for motorcycles using micro-simulation modelling have been reported to date and they are limited to freeway section and other type of vehicles. It should be noted however that micro simulation based methodology is highly sensitive and needs many parameters for calibration and validation. The more parameters are available for the calibration of driving cycle, the higher the accuracy would be. The difference in real world and observed is explained in the Table 11.2. However, the comparison should be taken with care, since there are a number of factors, which affect the accuracy of the results.

Table 11.2 presents the value of assessment parameters of EMDC and simulated driving cycles. Before any further comparisons are made between these two sets of results, the following factors have to be considered:

(a) Geographical characteristics of modelled corridor in VISSIM: Modelled corridor is restricted to the AQMA test section, whereas the routes used to derive the EMDC were spread over the whole city, covering north south, and east–west corridors. Modelled corridor is limited to urban area where as EMDC was covering both urban and rural area of Edinburgh.

(b) Length of the corridor: The length of the corridor, which is used to simulate the driving cycle, was restricted to 4.1 km, whereas the length of EMDC ranged from approximately 3-31 km.

(c) Type of engine size: To develop a simulated driving cycle, only one type of motorcycle has been defined, because engine size distribution for motorcycle type is restricted in VISSIM. Whereas five different types of engine sizes were used in developing the EMDC.

(d) Driving behaviour: There are only four components of driving behaviour in simulation environment of VISSIM. Many factors can influence the driving behaviour of motorcycles in real world (Lee, 2008). In order to investigate the impact of each of these factors on the driving cycle and its parameters an unmanageable number of runs, with different random seeds, would be required.

Due to the time and resource limitations during this study, a limited numbers of runs as well as a limited number of random seeds were implemented. This will certainly affect the accuracy of the results. The limited parameters (following, lane change, lateral behaviour) which were available in VISSIM were changed with a number of different seeds.

(e) Signal control: The major part of the simulated test corridor is controlled by the SCOOT system operated by Edinburgh City Council. SCOOT is the world's leading adaptive traffic control system. It coordinates the operation of all the traffic signals in an area to give good progression to vehicles through the network. Whilst coordinating all the signals, it responds intelligently and continuously as traffic, flow changes and fluctuates throughout the day. It removes the dependence of less sophisticated systems on signal plans, which have to be expensively updated. Therefore, the signal cycle data collected from the video on the corridor was static and does not represent the real world signal cycle length for whole day.

(f) Time of survey: The survey time of signal controller and traffic video was carried out mostly in the evening peak or off peak time (see Appendix 10.2), whereas time of data collection for EMDC was mostly in a.m. and p.m. off-peak times, since the driver's aim was to avoid peak-hour congestion.

(g) Traffic assignment: The assigned traffic in simulated driving cycles represents average measured traffic volume over a short period of time, which does not represent the actual fluctuation in real-world traffic.

The following observations can be made, however, from comparing the values of driving cycle parameters for both the estimates (Table 11.2).

The average speed and average running speed in the simulated driving cycle was found to be nearly half that of the real-world driving cycle. The total cycle duration varies from 1010 seconds in the simulated driving cycle one to 770 second in real-world EMDC. This shows that more time is spent in idling for the simulated driving cycle. Therefore, the cycle time of the real world and the simulated cycles was not similar. Time spent in idling was about 18% of the total cycle time, which deviates noticeably from the real-world value (1.5%). The percentage of time spent in acceleration was found to be 24% as compared to 44.5 % in the EMDC. In contrast, percentage of time spent in deceleration for simulated was 28% as compared to 46.87 % in the EMDC. However, the cruising proportion of the EMDC was found to be 7.24%, extremely low compared to 29.45% for the simulated cycle. In the studied simulated environment, there is no representation of the SCOOT system and real world assignment of traffic volume on all the arms, therefore the results deviate strongly. The number of changes in acceleration and deceleration in one driving period in simulation was found to be much less than the real-world cycle. Since, drivers are sensitive to the traffic, signals, and other factors in the real world (Jensen, 1995; Mierlo, 2004).

11.3 Emission estimation from the simulated driving cycle

11.3.1 Integrating VISSIM results with NAEI database

In the UK, TRL has been responsible for the provision of the UK road transport emission factors (EF), and maintaining its database. Those emission functions were recorded over real-world drive cycles and are expressed in terms of average vehicle speed. Data from the ARTEMIS project were utilised in developing the EF. The first revision of UK road transport emission functions was done by TRL in 1999. Those emission factors were incorporated into Volume 11 of the Design Manual for Road and Bridges (DMRB) and the National Atmospheric Emission Inventory (NAEI). The old emission factors were revised as new test data became available.

The TRL database of vehicle emission factors for NO_X, PM_{10}, CO, HC, VOCs (including methane), benzene, 1, 3-butadiene, CO_2 and fuel consumption was prepared from a review and assessment of the new set of speed-emission coefficients as reported by TRL from their analysis of new emission test results on vehicles, meeting mainly Euro 1 and 2 standards (Barlow, 2001).

The TRL database provides the complete set of speed-emission factor coefficients for NO_X, PM_{10}, CO, HC, benzene, 1, 3-butadiene, CO_2 and fuel consumption in its most disaggregated form. Coefficients are provided for functions relating emission factors in grams per kilometre to average speed for all the different types and sizes of vehicles in the UK fleet, in all the categories of European emission standards from pre-Euro 1 (<1993) right through to Euro 4 (2005) as a function of average vehicle speed. The equations follow the standard form as follows in Equation 11.1:

$$E = k + av + bv^2 + cv^3 \ + d/v + e/v^2 + f/v^3$$ **--------------------------Equation 11.1**

Where v is the average speed (km h^{-1}), E is the emission rate (g/km) and k, a-f are coefficients.

NAEI revised the emission factors based on review and assessment of new factors for Euro 1 and 2 vehicles given in the TRL Database of Emission Factors, September 2001 (Barlow, 2001) and reconsideration of scaling factors for Euro 3, 4 vehicles by NETCEN. The details for EFs are given in Appendix 11 a-d. An example for the EF equation has been given in Equation 11.2 below —this summarises the emission factors of the pollutants observed using these coefficients and comparison has been made with real-world emission data. In this study, these factors were integrated with result of micro-simulation model to get the instantaneous emission.

$$EF(gm/kg) = (a + bv + cv^2 + dv^e \ + f.\ln(v) + g.v^3 + h/v + i/v^2 + j/v^3 \ ) * x$$

-----------Equation 11.2

Where EF is the emission factor for the pollutants and v is speed in km h^{-1}. The coefficient a - j are given in Table 11.3 below for motorcycles of engine size 600 cc (Euro 2) and BMW 1000 cc (1990 Pre Euro).

Table 11.3 Value of coefficients of TRL-based emission factors

	Pollutant CO										
Engine Size	a	b	c	d	e	f	g	h	i	j	x
1000 cc Pre-Euro	4.9700	0.0000	0.0015				0.0000	414.0000	-1196.0000	0.0000	1.0000
600 cc - Euro 2	9.2900	0.0000	0.0011				0.0000	490.0000	-1436.0000	0.0000	0.3100
	Pollutant HC										
1000 cc	0.4660	0.0000	0.0000					90.1000	0.0000	-1064.0000	1.0000
600 cc	0.1310	0.0000	0.0000				0.0000	55.0000	0.0000	-517.0000	0.5500
	Pollutant NOx										
1000 cc	0.1600	0.0000	0.0000				0.0000	0.7380	0.0000	0.0000	1.0000
600 cc	0.0960	0.0000	0.0000				0.0000	0.0000	0.0000	0.0000	1.3700
	Pollutant Fuel										
1000 cc	119.6300	-3.6300	0.0480				-0.0002	0.0000	0.0000	0.0000	1.0000
600 cc	79.9000	-2.4600	0.0340				-0.0001	0.0000	0.0000	0.0000	1.0000

(Source: NAEI Database, 2009)

Where a, b, c, d, e, f, g, h, i, j, x are the respective emission coefficient (Equation 11.2).

The emission estimated because of the traffic activities on the corridor are presented in Table 11.4 and shows the variation of CO, HC and NO_X across the corridor in terms of maximum and minimum values.

Table 11.4 Observed emission factors from simulated driving cycle using NAEI coefficient

gm/km	Average emission factor	Maximum	Minimum	Standard Deviation
CO	26.7	40.78	16.52	45.11
HC	1.72	3.09	0.50	0.42
NO_X	0.28	0.83	0.25	0.06
CO_2	151.89	245.14	75.42	25.84

11.3.2 Variation in CO emissions

The minimum value of the CO emission factor was 16.52 gm km $^{-1}$, where as the maximum value was 40.78 52 gm km $^{-1}$. The average value of this emission factor was 26.7 52 gm km $^{-1}$. The standard deviation was 45.109, three times the minimum value, which shows that CO variation is highly affected by the stop-and-go operations. The variations of CO along the route are shown in Figure 11.3.

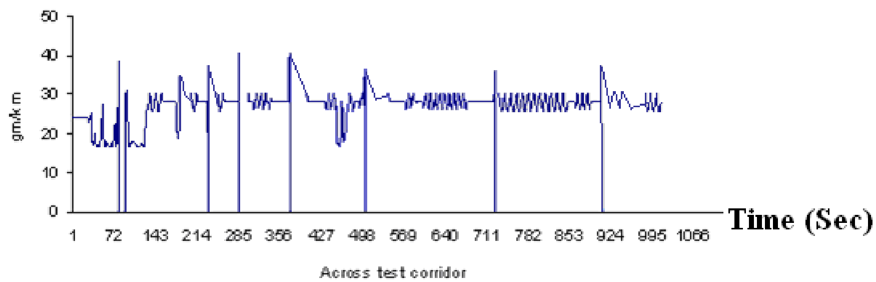


Figure 11.3 Variations of CO across the modelled corridor

11.3.3 Variations of HC emissions

The minimum value of the HC emission factor was 0.5 gm km $^{-1}$, whereas maximum value was 3.09 gm km^{-1}. The average value of the emission factor was 1.72 gm km^{-1}. The standard deviation was 0.415, which shows that HC varies six times of minimum along the corridor. The reason for this is the stop-and-go driving, frequent change in speeds and accelerations. The variations of the HC emissions along the route are shown in Figure 11.4**.**

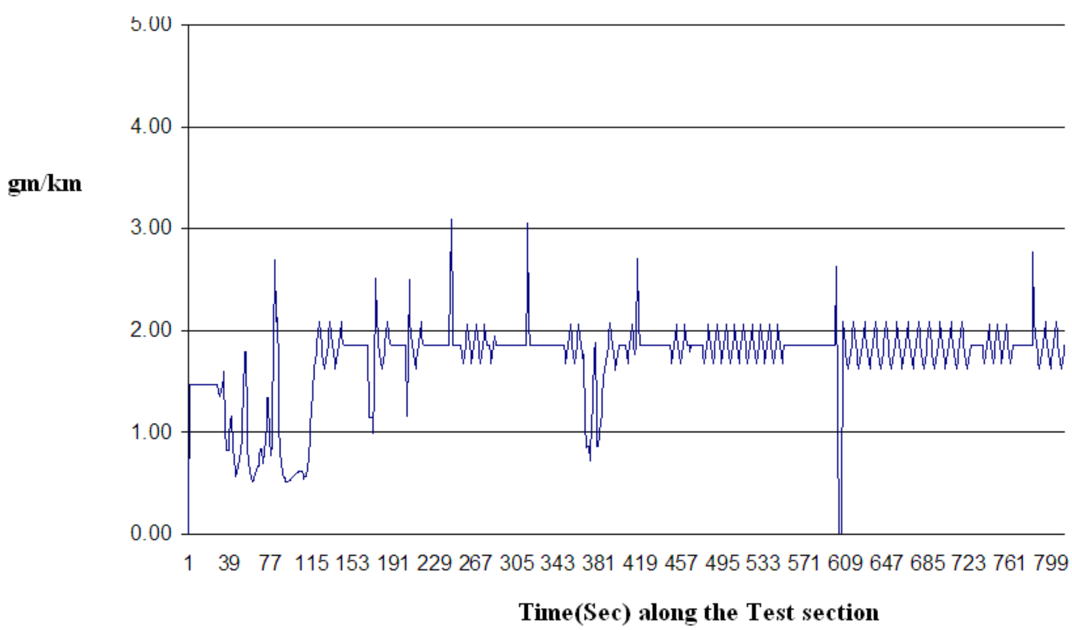


Figure 11.4 Variations of HC emission across test sections

11.3.4 Variations of NOX emissions

The minimum value of the emission factor was 0.5 gm km^{-1}, whereas the maximum was 3.09 gm km^{-1}. The average value of emission factor was 0.283 gm km^{-1}. The standard deviation was 0.415, which shows that NO_X varies six times of the minimum across the street. The reason is stop-and-go behaviour, frequent change in speed and acceleration at intersection. The variation of NO_X across the route is shown in Figure 11.5.

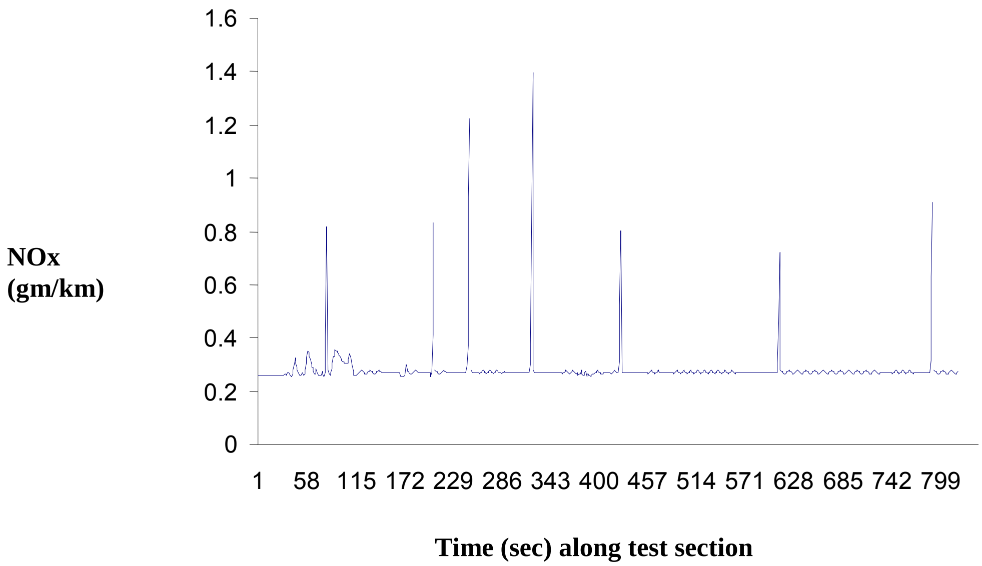


Figure 11.5 Variation in NO_X

11.3.5 Variations of CO_2

The minimum value of emission factor was 75.2 gm km^{-1}, whereas the maximum was 245.14 gm km^{-1}. The average value of emission factor was 151.89 gm km^{-1}. The standard deviation was 25.84, which shows that CO_2 varies three times of the minimum across the street due to the stop-and-go driving and frequent changes in speed and acceleration at intersection. The variation of CO_2 across the route is shown in Figure 11.6.

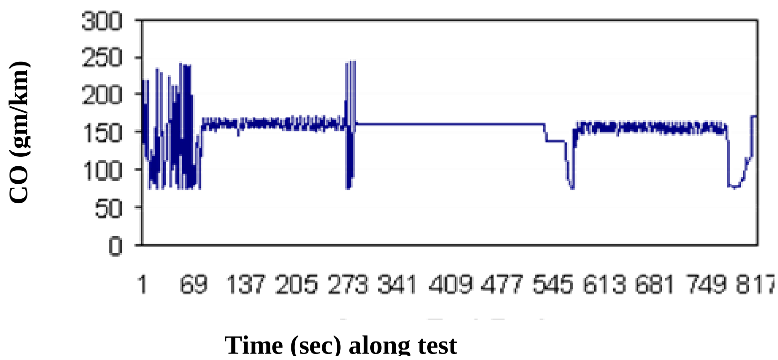


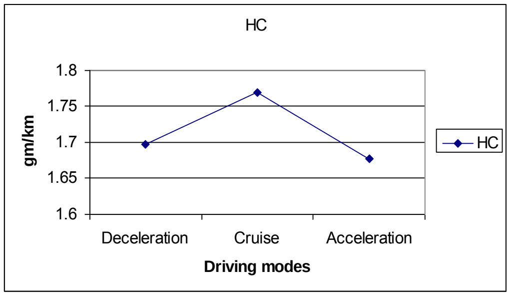
Figure 11.6 Variation of CO_2

11.4 Effect of driving modes on emission

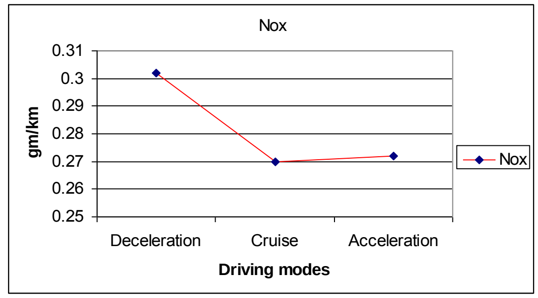
The quantities and composition of emission products from vehicles depend on the modes of driving. Normally, when the test vehicle is started from cold, the fuel enrichment increases that provides an easily combustible mixture near the spark plug. The four modes of driving have been classified based on the parameters defined in Table 8.7. The simulated driving cycle has 18.46 % of time spent in idling; time spent in deceleration and acceleration is almost equal. The NAEI coefficients do not validate for speed less than 0-3 km h^{-1} (Barlow, 2001). Therefore, emission data in idling mode is not calculated, although the analysis of this data shows that there is increase in emission factors during cruising mode except in the case NO_X (Figure 11.7).

Table 11.5 Average emission factors each of the driving modes along the simulated corridor

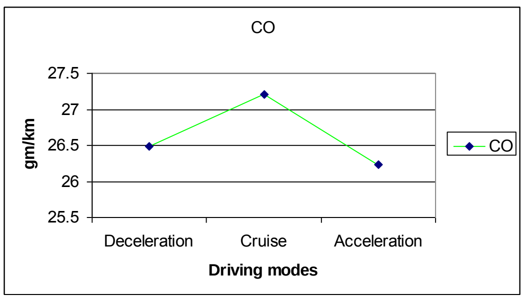
(gm/km)	Deceleration	Idling	Cruise	Acceleration
HC	1.70	-	1.77	1.68
CO	26.49	-	27.21	26.23
CO_2	152.07	-	154.75	148.22
NO_X	0.30	-	0.27	0.27
Total (sec)	282.00	185.00	292.00	243.00
% time spent	28.14	18.46	29.14	24.25



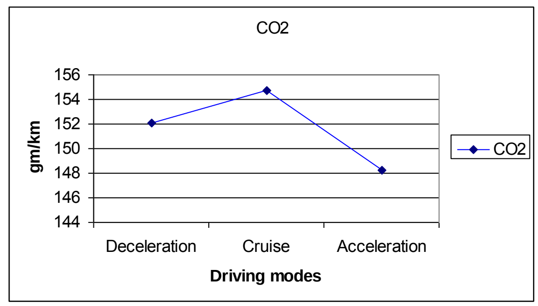
a)



b)



c)



d)

Figure 11.7 Effect of driving modes on emission factor

11.5 Summary

Micro simulation based driving cycle model was investigated for the 4.1 km length along the AQMA corridor. The results obtained from the AQMA test sections were both calibrated and validated for their frequency of speed level along the corridor. The GEH statistic was used to assess the statistical significances of the results. The comparison of EMDC to the simulated driving cycle provides useful tool to assess the results in the absence of real world driving cycle. However, it should be noted that the modelled simulated driving cycle was subject to many assumptions and therefore the results should be looked at with care. The emission estimates were calculated using the NAEI emission coefficients for the simulated driving cycle along the corridor in different driving modes using instantaneous speed. The results and discussion are discussed in Chapter-12.

CHAPTER 12 RESULTS AND DISCUSSIONS

12.1 Introduction

Data analysis and characteristics of driving cycles, emission measurements, and micro-simulation studies have been discussed in the previous chapters. This chapter presents an overall discussions of the results obtained in the study. These include discussion of the results of the driving cycle in Edinburgh, comparison of emissions measured from different driving cycles, results obtained from onboard emissions and lab and simulation modelling of emission estimations. The results are also discussed and evaluated with reference to emission standards for regulatory driving cycles.

12.2 Edinburgh motorcycle driving cycle (EMDC)

The driving cycle is a representative plot of driving behaviour in a particular city or a region and is characterized by speed and acceleration. A driving cycle consists of a sequence of several vehicle-operating conditions (idle, acceleration, cruise and deceleration) and is considered as a signature of driving characteristics of that city or region. The typical characteristics of developed EMDC for local (urban and rural) conditions have been investigated in this study.

The average speeds of EMDC in the urban and rural area were found to be 33.5 km h^{-1} and 49.73 km h^{-1}, while the average trip lengths were 7.3 km and 9.1 km respectively. The average cycle lengths for the urban and rural EMDC were 769.63 and 656.37 seconds respectively. The average time spent in urban acceleration (Pa), deceleration (Pd) cruise (Pc) and idling (Pi) were found to be 44.45%, 46.87%, 7.246%, 1.51% respectively, whereas the average time spent in rural acceleration (Pa), deceleration (Pd), cruise (Pc) and idling (Pi) were found to be 44.7%, 46.32%, 8.28% and 0.77% respectively. Details of the other characteristics of the EMDC are also discussed in Chapter 7.

12.2.1 Speed-acceleration probability distributions (SAPD) of EMDC

A convenient method to characterise vehicle modal events is to set up a speed/acceleration matrix (Watson et al., 1985; Hansen et al., 1995; Kishi et. al., 1996; Zachariadis et al., 1997). The speed/acceleration matrix gives the instantaneous emissions and fuel consumption rates for different combinations of instantaneous speed and acceleration. For each cell of speed and acceleration, the emission or fuel consumption rates are averaged to give a mean value. Therefore, investigation of the SAPD in driving cycles is very valuable. The SAPDs of EMDC urban and rural are shown in Figures 12.1 and 12.2 respectively.

The EMDC rural plot shows that speeds were observed more frequently in the range of 40-60 km h^{-1}, while a large proportion of acceleration was found in the range of 0 to 1 ms^{-1}. In the EMDC urban cycle, there are fewer long idle periods and relatively gentle acceleration and deceleration. The mean concentration of deceleration was found in the range of 0 to -1 ms^{-1} at 30-40 km h^{-1}, whereas in the rural EMDC the overall SAPD showed a large proportion of acceleration and deceleration at higher speeds (40 to > 60 km h^{-1}). The total number of deceleration events was found to be lower than acceleration events in EMDC rural. This is because the selected representative rural routes have less signals and stops and a higher speed limit (70 mi h^{-1} = 112 km h^{-1}). This allows drivers to accelerate and cruise more and have free driving as compared to urban EMDC.

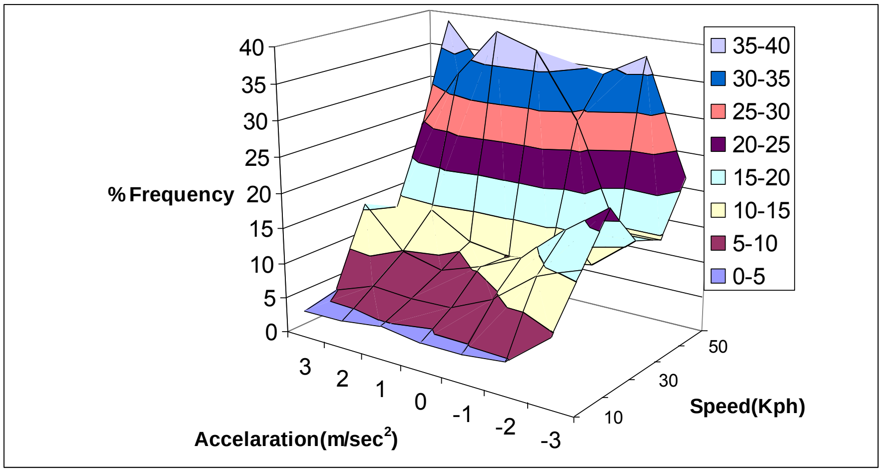


Figure 12.1 SAPD plot of EMDC urban

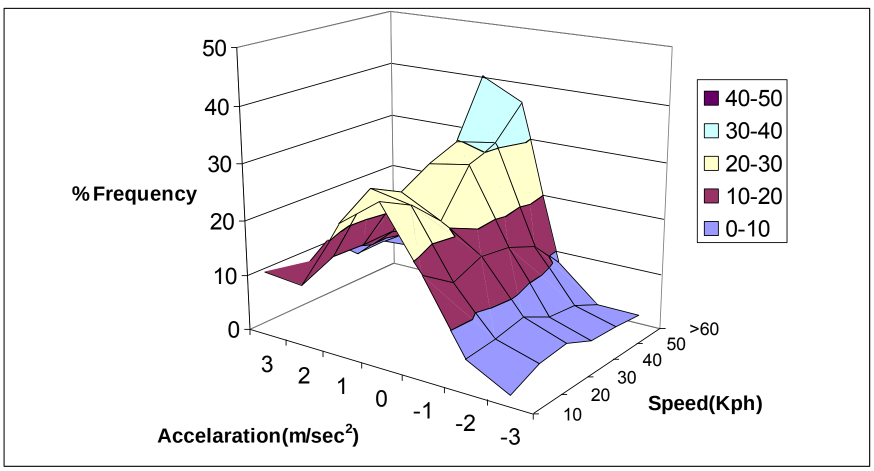


Figure 12.2 SAPD plot of EMDC rural

12.2.2 *Comparison of the EMDC with other driving cycles*

The driving patterns vary from one city to another and from region to region. Consequently, the driving cycles developed in a certain region may not be a good representation elsewhere unless the driving characteristics are conspicuously similar (Kamble, 2009). Therefore, a comparison of driving cycle parameters is useful. In this section the values of EMDC driving cycle parameters has been compared with other driving cycles, e.g. EDC, WMTC, Kaosiung Driving Cycle (KHM), URB, Taipei, Taichung, Pingtung and ECE. Direct comparisons, however, may not be very effective due to the differences in adopted factors (i.e. environment, traffic volume, road conditions, arrangements and phasing of traffic signals and driver habits) (Chen et al., 2003). However, such a comparison can throw up useful insights regarding actual and simulated driving cycles.

(a) Comparison of time spent in different driving cycles

The vehicle engine operating modes are divided into idling, accelerating, cruising and decelerating activities. Figure 12.3 shows idle and cruise times spent in the EMDC. These were found to be lower than their similar European driving cycle like ECE, EDC, WMTC and other Asian driving cycles for Taiwan (KHM, URB, Taipei, Taichung and Pingtung). For example, time spent in idling for the EMDC (urban) is about 1.51% (the lowest in all driving cycles), while it is just under 30% in the EDC. The highest time spent in cruising was in the WMTC Part 3 section (about 55%), while the lowest was in the EMDC (rural) which is 8.28%. This means that motorcycle driving in Edinburgh is characterised by more frequent acceleration and deceleration than cruising. Therefore, the time spent in acceleration and decelerations in the EMDC were found to be higher than in the other driving cycles.

(b) Comparison of average speed

As shown in Figure 12.4, the average cycle speed of the EMDC urban was higher than most other driving cycles, including the EDC. The average cycle speed of the EMDC rural (49.73 km h^{-1}) is exceeded only by the WMTC Part 2 and Part 3. This interesting result indicates that only other driving cycles would not represent the typical driving characteristics of motorcycles in Edinburgh adequately.

(c) Comparison of cycle durations

Figure 12.5 shows the total cycle duration of the EMDC (urban and rural) as well as for the standard cycles. It appears that KHM has a maximum duration of 1600 seconds, while ECE has a minimum duration of 195 seconds. The total cycle duration of EMDC (urban) is lower than that of the EDC, but they were both slightly higher than the WMTC and much higher than the ECE. The duration for the EMDC (rural) was higher than the WMTC (parts 1-3) and the ECE, but lower than that of the EDC. All of the above comparisons show that driving cycle characteristics are very specific to the local conditions of the investigated area and cannot simply be adopted in another area without careful consideration.

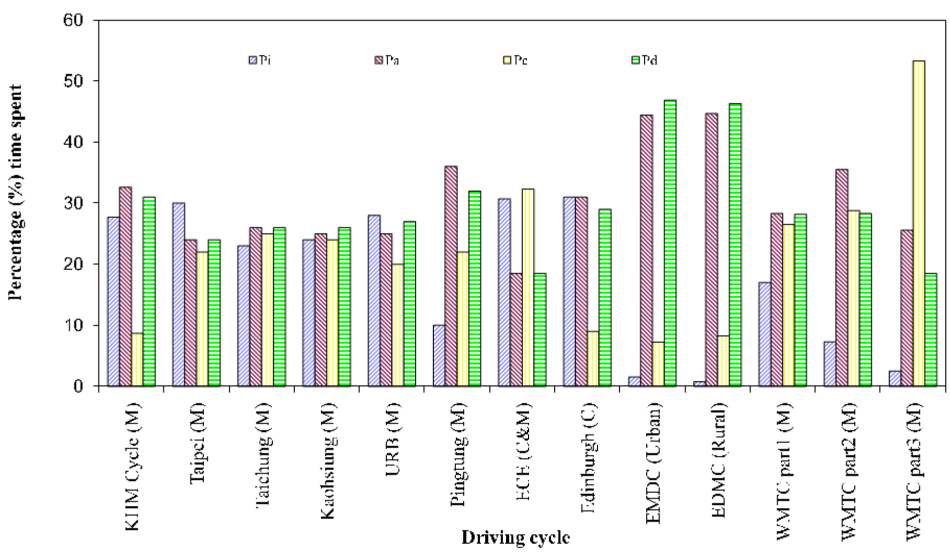


Figure 12.3 Comparison of time spent in each of the vehicle operating modes of EMDC and other driving cycles in some Asian and European cities.

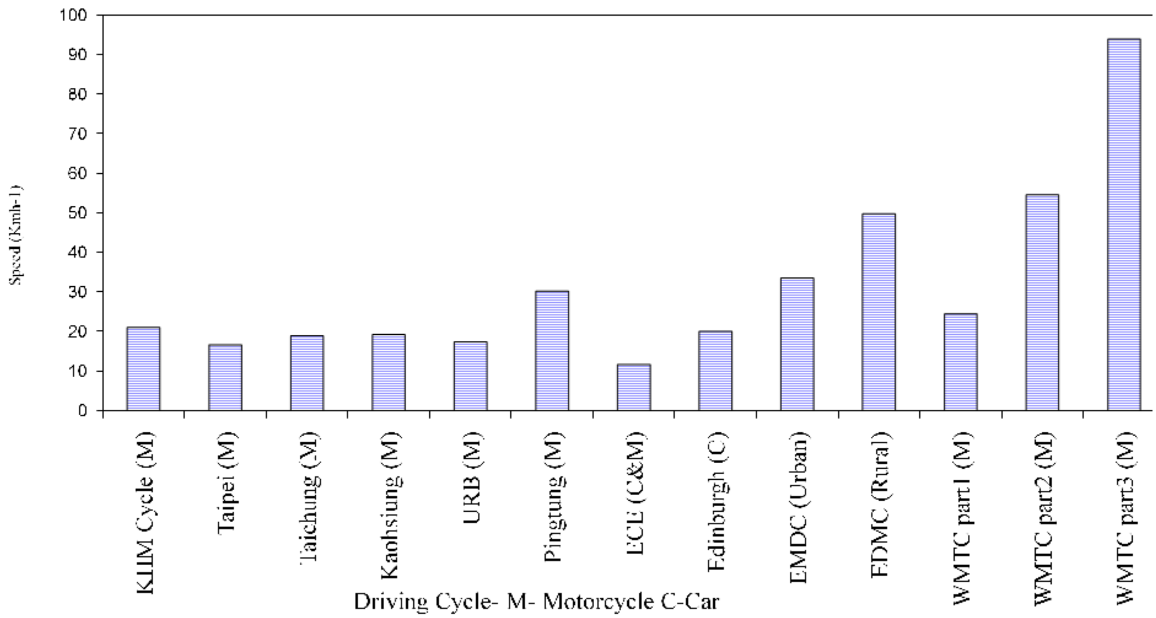


Figure 12.4 Average speeds (km h^{-1}) during different driving cycles

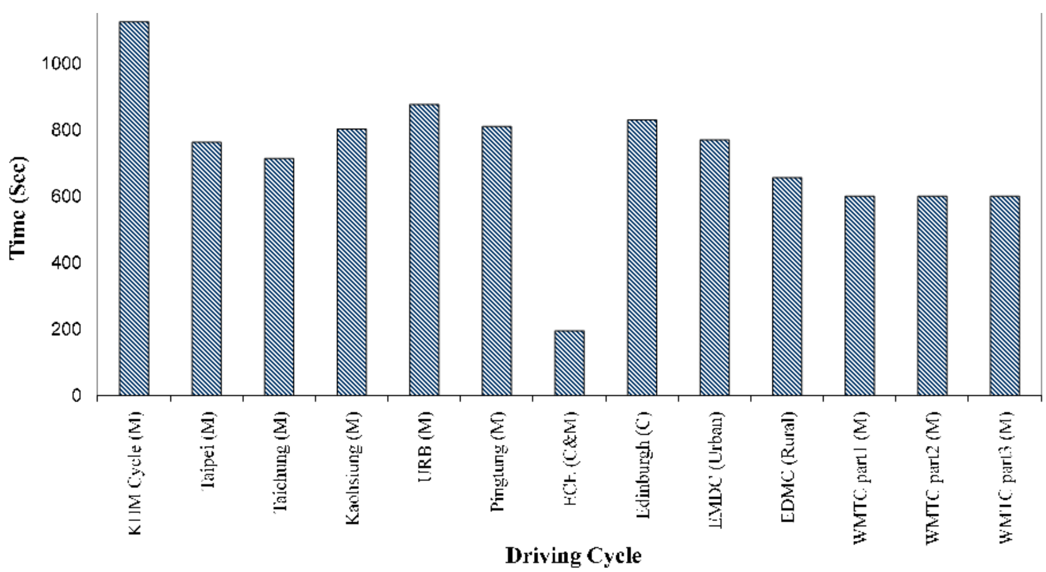


Figure 12.5 Cycle durations (sec) during different cycles

(Note: M and C represent motorcycles and cars)

12.3 Adopted emission measurement approaches for motorcycle emissions

The main objective of the study was to develop the local real-world driving cycle for motorcycles for Edinburgh and find out the emission factors for the local conditions. In the UK, emission factors from TRL (Barlow, 2001) are used by manufacturers for emission certification standards. Although this database doesn't include any motorcycle driving data from Scotland or the Edinburgh region, still the comparison of emission factors based on instantaneous speed in local driving conditions are good (see NAEI database-Appendix 11.1 a-d). In our investigation, emission factor estimates were calibrated by using three different approaches: (a) Onboard emission measurements (b) Emission measurements using chassis dynamometer; (c) Emission estimation using micro-simulation modelling. All of the three approaches were applied on local driving characteristics in Edinburgh city. The aim is to access and to evaluate the use of standard emission factors to represent local condition.

12.3.1 Emission estimation using onboard emission measurement

Onboard emission measurements were made along the AQMA. Emissions and speed data were collected using two motorcycles (1000 cc and 600 cc). The measured CO, HC and NO_X emissions using onboard equipment were first analysed using the carbon mass balance methods. Then these emissions were expressed as gm per km (see for details Chapter 8 and 9). CO, HC and NO_X emissions (gm/km) for 1000 cc engines were found to be 3.055, 0.038 and 0.009 respectively, whereas CO, HC and NO_X emission (gm/km) for 600 cc engines were found to be 1.757, 0.041 and 0.004 respectively (see Table 12.1).

Measured instantaneous speeds during onboard measurements were also used to estimate the emission factors in local conditions using the NAEI factors. This is available as a tool for the modeller to check and seek deviations in emission factors. However, emission factor estimations, using the onboard measurement approach provides an edge to check the performance of high polluter/emitter motorcycles in the real world, which is not possible to estimate solely by using the NAEI emission coefficients, as these coefficients are based on speed only (Appendix 11.1). These coefficients do not take account of other factors such as engine management systems, engine technology, and age of the motorcycle and maintenance aspects.

12.3.2 Emission estimation using micro-simulation approaches.

The micro-simulation approach is useful to estimate the emissions in the absence of onboard measurement or laboratory measurement. This approach (in-house model building) required many inputs from secondary sources. An essential input to this was the model building of motorcycle vehicle and the assignment of it over corridor to the other, creating the required characteristics of a motorcycle lane and changing driving behaviour parameters. Finally, the model was calibrated and validated using the real-world speed–time data collected over the corridor. Instantaneous speed data was extracted using micro-simulation approach for the same selected test corridor used for onboard data collection on the AQMA. Emission factors were then estimated using the instantaneous speed for each of two motorcycles, The average value of CO, HC and NO_X emissions (gm km^{-1}) for the 1000 cc engine were estimated 26.7, 1.72 and 0.283 respectively, whereas CO, HC and NO_X emissions (gm km^{-1}) for 600 cc were 10.581, 1.90 and 0.283 respectively (see Table 12.1). It should be noted here that while micro-simulation modelling has been widely used as a tool to model various traffic and transport scenarios, the results from simulation modelling should be taken with great care. All the outputs are based on the assumptions implied in the models.

12.3.3 Emission estimation using chassis dynamometer in laboratory

One of the main aims and applications of chassis dynamometer tests is to replicate the actual drive cycle of the vehicle journey route in terms of vehicle speed against time. The exhaust emissions generated for the specified driving cycle using a vehicle speed versus time trace on a chassis dynamometer represent the tailpipe-out emission levels for a given route. The amount of emissions produced at every instant can vary largely over the duration of a journey and this depends upon the nature of driving traffic conditions, road network and road geometry (Samuel, 2002). This is done in the controlled environment of the laboratory. In our study, the driving cycles (such as EMDC, ECE and WMTC) were used to measure the emission factors for CO, HC and NO_X for the two engine sizes (1000 cc and 600 cc). The results obtained from these tests are presented in Table 12.1; details about the emission factors are also discussed in Chapter 9. The average emission factor for CO was found in the range of 9 to 40 gm km^{-1}. The highest CO emission value was 36.9 gm km^{-1}, whereas the lowest was 9.4 gm km^{-1}. For larger engine sizes, CO emissions were more. The average emission factor for HC was found in the range of 1.5 to 4.9 gm km^{-1}; the highest HC emission value was 4.4 gm km^{-1} for EMDC urban, whereas the lowest was 1.2 gm km^{-1} for WMTC measured part 3. For the smaller engine size, HC emission was higher in the EMDC urban cycle. The average emission factor for NO_X was found in the range of 0.1 to 0.5 gm km^{-1}; the highest NO_X emission value was 0.6 gm km^{-1} for WMTC measured part 3, whereas the lowest was 0.1 gm km^{-1} for EMDC rural. The NO_X emissions were higher fir the larger engine size.

12.4 Evaluation criteria for emission measurement approach

It is clear from the above discussions that measuring emissions from different approaches resulted in different emission factors. The evaluation of these approaches is important from a user and application point of view. For the evaluation of those approaches, it is necessary to set an evaluation criteria; the evaluation should be done with reference to regulatory emission standards to assess the real-world emission variations in the local conditions. Regulatory emission standards for motorcycles have been in place since 1999, and implemented in three stages: Euro 1 (from 1999), Euro 2 (from 2003) and Euro 3 (from 2006) with the WMTC standard in place since 2006 onward. In this section, four regulatory standards are used to set up evaluation criteria to compare and assess the results obtained from the different measurement approaches for emission estimation. The percentage deviations between emission factors obtained from different emission measurements and regulatory emission standard are presented in Tables 12.2 and 12.3 for the urban and rural driving cycles respectively.

Table 12.1 Emission factors measured on different driving cycles

Sources	Pollutant	CO (gm km^{-1})		HC (gm km^{-1})		NO_X (gm km^{-1})	
	Engine size	600 cc	1000 cc	600 cc	1000 cc	600 cc	1000 cc
Regulatory standard	WMTC standard urban	2.62	2.62	0.75	0.75	0.17	0.17
	WMTC standard rural	7.40	7.40	0.50	0.50	0.10	0.10
	WMTC standard highway	2.90	2.90	0.20	0.20	0.50	0.50
	Euro 1 standard	8.00	8.00	4.00	4/00	1.00	1.00
	Euro 2 standard	5.50	5.50	1.00	1.00	0.30	0.30
	Euro 3 standard	2.00	2.00	0.30	0.30	0.20	0.20
Measured in laboratory	ECE 40 measured	15.90	34.20	2.40	2.80	0.10	0.20
	EMDC rural	9.40	36.90	1.60	1.50	0.10	0.10
	EMDC urban	13.10	44.10	4.40	3.70	0.20	0.30
	WMTC measured part- 1	10.00	36.80	3.0	3.00	0.10	0.10
	WMTC measured part -2	17.60	43.20	1.90	1.80	0.10	0.20
	WMTC measured part -3	34.90	38.00	2.10	1.20	0.20	0.60
Using Onboard emission approach	Using analyser	1.76	3.05	0.04	0.04	0.01	0.01
	Using NAEI emission coefficient	8.28	21.80	1.34	1.21	1.54	0.39
Micro-simulation approach	Using NAEI emission coefficient	10.58	26.70	1.90	1.72	1.14	0.28

Table 12.2 Percentage deviations from regulatory standards for urban driving conditions

Driving cycle	Regulatory Standard					
	% Deviation from WMTC standard					
Pollutant	CO (gm km^{-1})		HC (gm km^{-1})		NO_X (gm km^{-1})	
Engine Size	600 cc	1000 cc	600 cc	1000 cc	600 cc	1000 c
ECE 40 measured	**506.87**	1205.34	220.00	273.33	-41.18	17.65
EMDC urban	**400.00**	**1583.21**	**486.67**	**393.33**	17.65	76.47
WMTC measured - part1	281.68	1304.58	300.00	300.00	-41.18	-41.18
Onboard emission using analyser	-32.94	16.53	-94.67	-94.93	-95.29	-97.65
Onboard emission using NAEI emission factor	216.03	732.06	78.67	62.13	**808.24**	**134.71**
Micro-simulations	303.82	919.08	153.33	129.33	**570.59**	**66.47**
	% Deviation from Euro 1 standard					
ECE 40 measured	**98.75**	327.50	-40.00	-30.00	-0.90	-0.80
EMDC urban	**63.75**	**451.25**	**10.00**	**-7.50**	-0.80	**-0.70**
WMTC measured - part1	25.00	360.00	-25.00	-25.00	-0.90	-0.90
Onboard emission using analyser	-78.04	-61.84	-99.00	-99.05	-0.99	-1.00
Onboard emission using NAEI emission factor	3.50	172.50	-66.50	-69.60	**0.54**	**-0.60**
Micro-simulations	32.25	233.75	-52.50	-57.00	**0.14**	**-0.72**
	% Deviation from Euro 2 standard					
ECE 40 measured	**189.09**	521.82	140.00	180.00	-66.67	-33.33
EMDC urban	**138.18**	**701.82**	**340.00**	270.00	-33.33	**0.00**
WMTC measured - part1	81.82	569.09	200.00	200.00	-66.67	-66.67
Onboard emission using analyser	-68.05	-44.49	-96.00	-96.20	-97.33	-98.67
Onboard emission using NAEI emission factor	50.55	296.36	34.00	21.60	**414.67**	**33.00**
Micro-simulations	92.36	385.45	90.00	72.00	**280.00**	**-5.67**
	% Deviation from Euro 3 standard					
ECE 40 measured	**695.00**	1610.00	700.00	833.33	-50.00	0.00
EMDC urban	**555.00**	**2105.00**	**1366.67**	**1133.33**	0.00	**50.00**
WMTC measured - part1	400.00	1740.00	900.00	900.00	-50.00	-50.00
Onboard emission using analyser	-12.15	52.65	-86.67	-87.33	-96.00	-98.00
Onboard emission using NAEI emission factor	314.00	990.00	346.67	305.33	**672.00**	**99.50**
Micro-simulations using NAEI	429.00	1235.00	533.33	473.33	**470.00**	41.50

(Bold figures show highest deviation.)

Table 12.3 Percentage deviations from regulatory standards for rural driving conditions

Pollutants	CO (gm km^{-1})		HC (gm km^{-1})		NO_X (gm km^{-1})	
Engine Size	600 cc	1000 cc	600 cc	1000 cc	600 cc	1000 cc
% Deviation from WMTC						
EMDC rural	27.03	398.65	220.00	200.00	0.00	0.00
WMTC measured Part 2	137.84	**483.78**	**280.00**	**260.00**	0.00	100.00
% Deviation from Euro 1						
EMDC rural	17.50	361.25	-60.00	-62.50	-90.00	-90.00
WMTC measured Part 2	120.00	**440.00**	-52.50	-55.00	-90.00	-80.00
% Deviation from Euro 2						
EMDC rural	70.91	570.91	60.00	50.00	**-66.67**	-66.67
WMTC measured Part 2	220.00	**685.45**	**90.00**	**80.00**	**-66.67**	**-33.33**
% Deviation from Euro 3						
EMDC rural	370.00	1745.00	60.00	50.00	-66.67	-66.67
WMTC measured Part 2	**780.00**	**2060.00**	**90.00**	80.00	-66.67	**-33.33**

12.5 Comparisons of emission factors deviations

Respective percentage deviations between regulatory standards (Euro and WMTC) and measured emissions factors of CO, HC and NO_X are presented in Tables 12.2 and 12.3 respectively.

12.5.1 Comparisons of emission factor deviations under different driving cycles

The percentage deviation for CO and HC emission factors estimated for the lab EMDC urban cycle did not meet regulatory standard norms and these values were too high and deviated too much from current emission factors of regulatory standards. The results obtained from measured emission factors indicate that EMDC urban has higher emission factors compared to standard regulatory emission factors. This gives good justification for deriving the driving cycle in local condition for emission estimates.

In contrast, lab measurement of the EMDC rural cycle showed less variation in emission factors compared to the urban one. Deviations of results for EMDC rural were found to be lower than WMTC part 2 as measured in the lab, when compared to the WMTC and Euro emission standard evaluation criteria. This shows that EMDC rural is not very dynamic when it is compared to WMTC part 2 for the rural cycle (see Table 12.3).

Onboard emission factor for NO_X using TRL coefficient also showed larger percentage deviation in the similar pattern of the EMDC driving cycle, reflecting the effect of the local driving cycle. However, the overall consistency of the EF results is sensitive to both the type of pollutant and the driving cycle; e.g., the NO_X in the EF results are more consistent than those of the other pollutants.

12.5.2 Comparison of emission factors based on different approach

(a) CO and HC Emission Factors

CO emission factors (EF), using lab and micro-simulation approach, did not meet the current emission factors of regulatory standards. In fact, in some of the cases lab measurements exceeded the standard by 2100%. For example CO (gm km^{-1}) measured in the lab deviated 2100% from the current Euro 3 standard for 1000 cc motorcycles. Higher deviations of lab results were observed for WMTC and Euro 3 (see Tables 12.1 and 12.2) since these EF standards are the latest and stricter than the old Euro 1, Euro 2 and pre-Euro standards. Also, emissions shoot up in real world driving in EMDC due to a higher percentage of acceleration and deceleration (see Chapter 9). Laboratory-based emission factors for CO and HC for EMDC urban were found to be higher than that obtained from micro-simulation and onboard emission, whereas the emission factors obtained from micro-simulation and onboard emission using the NAEI database were reasonably similar except for the NO_X emission factor.

(b) NO_X Emission Factor

Emission factors for NO_X pollutant obtained using the onboard emission and micro-simulation approaches (applying NAEI emission coefficient) exceeded all regulatory EF standards.

EF of NO_X obtained from the onboard emissions and micro-simulation using NAEI emission coefficients did not show much variation between them, since both EFs were estimated based on the real-world driving speeds of motorcycles in the AQMA corridor in Edinburgh.

One of the important reasons that emission factors were calculated based on the instantaneous speed rather than average speed in the onboard and micro-simulation approach is because it make more realistic estimates of EF. Even NO_X emission factors for the lab urban EMDC was found to be different (ranging from 0.15% to 800%) from the regulatory (Euro and WMTC). The effect of real world driving on NO_X emissions is clearly reflected in the fact that the differences are caused by formation of a lean air-fuel ratio due to the excessive engine-temperature from the frequent acceleration and deceleration pattern observed in Edinburgh.

(c) Discussion of comparison of results

The micro-simulation approach requires many input parameters such as vehicle loads, slopes, signal cycle, traffic input, road geometry and gear shift scenarios to derive the realistic driving cycle in local conditions (Delia and Martin, 2005). The results obtained from the micro-simulation based driving cycle for motorcycles of current study has been calibrated and validated with the real-world driving data of motorcycles (Chapter 11). The emissions (in gm per km) for this approach are estimated using the emission coefficients of the NAEI database, which is based on emission coefficients as a function of speed. The latest emission coefficients of the NAEI database were developed by repeating several test conditions on chassis dynamometers for different engine sizes of motorcycles (NAEI, 2007). The advantage of applying such a coefficient in the micro-simulation approach is to do visual checks of emissions second-by-second using the speed data collected per second along the corridor, which can be further used to estimate the emissions during different driving modes. This can also be used to identify the hot spot locations for emissions along the corridor.

From the analysis of all the emission measurement approaches, emission factors obtained from onboard emission measurement for all pollutants were found to be lowest. Such type of result comparisons allowed us to identify the conversion problems in gm km^{-1} or calibration errors, as well as time alignment problems during the sampling and measurement process.

During the estimation of onboard emission factor, many factors contributed to under-estimation of results. Those factors were: (a) crude estimates of fuel consumptions; (b) dilution of the measured gases in the ambient atmosphere during the application of the gas analyser in open exhaust pipe; (c) the analyser going offline due to its limited logging period (60 minutes of PMGA) and; (d) the synchronisation issues with data logging in the PMGA and PB — these all had an impact on the accuracy of the results. These factors could be not being controlled during the emission measurement due to resources and time limitations. Therefore, the results from onboard estimation were not comparable from the laboratory and micro-simulation based emission factor estimates.

However, the onboard approach has advantages over laboratory and micro-simulation based measurements because this provides the real-world fluctuation of emissions in different vehicle operating modes. Concurrently, such type of variations cause lots of errors in estimation of emission factors. For example, Joumard (1995) reported onboard emission testing for cars in which, for instantaneous emission modelling, emission factor errors ranged from -51% to +57% depending on the driving cycle and the vehicle type. In instantaneous emission-modelling based on an engine power approach (emissions are determined as a function of engine demand and other physical parameters related to vehicle operations), errors in emission factors were reported in the range from -48% to +12%, depending on the considered emissions, driving cycle, or vehicle type (Joumard, 1995).

Reported study in published literature reports that instantaneous onboard emissions are hardly more precise than the laboratory-based measurement. Another drawback of the onboard emission approach is that it cannot take into account different gearshift scenarios or load variation. For example, during onboard emission measurements in our study, load on the motorcycle and style of driving pattern was kept as constant as possible by using the same volunteer driver and test corridor, so this also could be a further area of research.

In spite of all these limitations, the onboard emission modelling approach covers the variations in emissions occurring due to the factors that affect emission rates in the real-world driving environment. However, this type of modelling is highly complex due to the large amount of data required. Moreover, there were a large number of factors relating to the vehicle and road types—e.g. different engine technologies (fuel injection and carburettor based) and the road gradients — which could affect the results.

Laboratory-based measurement needs a controlled environment and precise control over the measurement process. It is also expensive (3 tests for 3 types of driving cycle costs £2000), which does not permit us to carry out more tests with limited resources. EF obtained from laboratory measurements were found to be higher as compared to micro-simulation and onboard emissions, because the real-world EMDC driving cycle were used in the emission estimation process, which is very dynamic in nature (having more acceleration and deceleration).

Finally, it was clear from the above analysis that emission factors for CO and HC emissions EMDC compared to ECE in the lab showed larger differences from the regulatory one; for the NO_X emission factor the micro-simulation approach showed larger deviation. In the absence of laboratory measurements the NAEI/TRL emission coefficients can be used, but with great care.

12.5.3 Comparison of emission factors based on engine sizes

The CO emission factor was found to increase with engine size (see Table 12.1). The increase was absorbed from 8% to 74% depending on the different driving cycles used in estimation. For HC emissions it was less sensitive than the CO pollutant; HC emission decreased with the increase in engine size. However, the influence of the driving cycle also affected the range of the decrease in emission factors.

For the NO_X emission factors, the effect of engine size was dependent on the emission measurement approach: laboratory emissions show an increase if engine size increases, while there is a decrease in EF if the TRL coefficient is used.

12.6 Summary

The speed/acceleration matrix is one of the convenient methods to characterise vehicle modal events in the driving cycle. Therefore, SAPDs have been plotted for the EMDC urban and rural driving respectively. In the urban EMDC, there are few long idle periods and relatively gentle acceleration and deceleration. The total number of deceleration events was found to be lower than acceleration events in the EMDC rural due to the selected representative rural routes having fewer signals and stops, and a higher speed limit (112 km h^{-1}). EMDC emission factors were highest for CO and HC among all the driving cycles.

There were four evaluation criteria defined to compare the differences obtained in different emission approaches. It was found that the emission factors for CO and HC pollutants using lab urban EMDC and micro-simulation approach did not meet the regulatory emission standards. The lab urban EMDC for NO_X showed reasonable deviation from standards, reflecting the effect of real world driving on emissions due to the lean fuel–air ratio caused by excessive engine temperatures associated with the frequent acceleration/deceleration patterns which were observed in Edinburgh. Emission factors for CO and HC emissions based on EMDC and ECE urban driving cycle measured in the lab showed large differences from regulatory levels; for NO_X emission factors, the micro-simulation approach showed larger deviation. In the absence of laboratory measurements, the NAEI/TRL emission coefficients can be used with great care.

CHAPTER 13 CONCLUSIONS AND RECOMMENDATIONS

13.1 Introduction

The driving cycle is a fundamental building block for studying traffic management schemes, measurement of fuel consumption and estimation of emissions accurately at local levels. Driving cycle research enables the establishment of firm and realistic regulations for automotive fuel and emissions on a national and international level. Driving characteristics of the motorcycle are significantly different from those of the private cars due to their ability to filter, moving ahead of the queues, and progressing parallel to other vehicles. European motorcycles have higher dynamic acceleration than cars due to higher power to mass ratio. In the past decades, very few studies have been reported to date on the actual driving characteristics of motorcycles and to real-world driving cycles in UK. Conclusions drawn from this detailed investigation and synthesis of the motorcycle driving cycle, emission measurement, and micro-simulation for Edinburgh are presented in this chapter.

13.2 Research conclusions

To investigate the research questions/hypothesis related to modelling of motorcycle driving cycles and emissions, four objectives have been set up. The original objectives (stated in Chapter 2) have evolved over the period of study as a result of availability of resources and material, the first refined objective for this research is:

to develop the driving cycle for motorcycles in Edinburgh for urban and rural driving conditions.

To assess the emissions from motorcycles under local conditions in Edinburgh both urban and rural driving cycles were developed using a number of assessment parameters.

Data collection of instantaneous speed, acceleration, deceleration, distance travelled and route tracking over five different routes were made which included both urban and rural roads encompassing the north–south and east–west corridors of Edinburgh.

The analysis of the derived Edinburgh motorcycle driving cycle (EMDC) in urban and rural real-world driving conditions demonstrated that motorcycle use and driving conditions differ significantly as regards to urban and rural driving conditions. Real-world Edinburgh motorcycle driving was found to have a typical transient nature of speed and acceleration, which was clearly different from the regulatory driving cycle (for example for Euro and WMTC).

From the results of the EMDC, the time spent in idling mode for the urban cycle was found to be greater than that of the rural, whereas time spent in cruising was found to be less than that is rural. The average cycle speed and the average running speed of the rural sections were both higher than those of the urban roads. The average speeds of motorcycles in the urban and rural were found to be 33.5 km h^{-1} and 49.73 km h^{-1} respectively. The average trip lengths for the urban and rural EMDC were 7.3 km and 9.1 km (seems short) respectively. A comparison of time spent in different vehicle operating modes (acceleration, deceleration, cruise and idling) with the regulatory and Asian driving cycles showed large differences. Another comparison with the urban EMDC to the Delhi MDC (DMDC) showed higher acceleration and deceleration rates in the EMDC. This implies that the urban EMDC has more frequent “stop and go” operations compared to the DMDC. The characteristics of EMDC reflected the presence of sports-type motorcycles with high power mass ratios; these have rapid and high acceleration rates, in contrast to those of the DMDC, which is comprised of small engine size motorcycles with lower positive kinetic energy.

The SAPD plot shows the range of driving speed patterns for the urban (speed range of 30-40 km h^{-1}) and rural (speed range of 40-60 km h^{-1}) sections. For these speed ranges, corresponding acceleration and deceleration were ranging from (0-1) m/sec^2 to (0 to -1) m/sec^2 respectively. The SAPD plot can be used to investigate the traffic speed and their fuel consumption behaviour in the city by policy enforcement of eco- driving. The second objective of this study was:

to analyse and compare the onboard emission measurement along the AQMA corridor and laboratory emission measurements from motorcycles using different approaches.

Onboard measurements enable quantification of emissions and pollutants with respect to location as well as with respect to micro-scale trip characteristics (vehicles and drivers) in real-world scenarios. Laboratory measurements only are inadequate due to attributed factors such as the limitations of the test-driving cycle, engine sizes and not meeting the high frequency of ‘off-cycle’ driving events under actual driving conditions. On-board emission testing under real-world traffic conditions offers an alternative approach for determining realistic emission rates, which should also be used as complementary tool to laboratory testing.

Onboard measurements of CO, HC, NO_X and lambda using the Probike Microgas Analyser were undertaken. Laboratory measurements of emissions were carried out on a number of driving cycles (for example, ECE, WMTC, urban and rural EMDC) using a chassis dynamometer. Speed and acceleration measurements along the test corridor were collected using the Performance Box.

Emission factors were estimated for two engine size (600 cc, 2004 model and 1000 cc, 1990 model) using both techniques and the results were analysed and compared.

It was possible to estimate the emissions during different vehicle operating modes by collecting instantaneous onboard emission data. CO emissions were found to be more sensitive to the power demand required during start conditions as well as under running conditions. This phenomenon was reflected by peaks under very high power demand. CO concentrations during these events can reach several percent of CO by volume, for example, 8.5% for 1000 cc as compared to 6% for 600 cc. CO emissions for the 1000 cc engine were 1.5 times higher than for the 600 cc. For smaller engines of 600 cc, CO emissions in deceleration modes were found to be 26% more than in acceleration modes.

While measuring onboard emissions the maximum speed along the test corridor was found in the range of 30-40 km h^{-1}, while the maximum positive acceleration and deceleration minima were found in the range of 0.2-0.3 m $sec^{-2,}$ and 0.1 to 0.2 m sec^{-2} respectively. The emission factor (EF) decreased with the increase of speed but once the speed crossed the range of 30-40 km h^{-1}, a slight increase in EF was observed. This shows the optimum operating speed for minimum emissions since burning efficiency improves above a certain speed, resulting in a decrease in emissions.

The instantaneous emission models were developed based on the relationship between instantaneous speed and the different emissions. The regression coefficients were calibrated with R^2 values greater than 0.86. These empirical relationships apply to other similar areas (at least in Edinburgh). Approximately 80% of the total CO, HC and NO_X emissions were attributed to acceleration and deceleration modes. The remaining 20% of CO, HC, and NO_X emissions resulted from the idling and cruising modes. Higher emissions were observed during decelerations from smaller engine sizes than from larger engine sizes.

Estimated CO, HC and NO_X emissions (gm km^{-1}) for the 1000 cc engines were found to be 3.055, 0.038 and 0.009 respectively, whereas these emissions (gm km^{-1}) for the 600 cc engines were found to be 1.757, 0.041 and 0.004 respectively using onboard emission measurements.

Emission factors were also estimated by using the emission measurement made in the laboratory under different driving conditions (e.g. EMDC, ECE, and WMTC). CO, HC, and NOx emission factors were found in the range of 9-40 gm km^{-1}, 1.5-4.5 gm km^{-1}, and 0.1-0.5 gm km^{-1} respectively from laboratory measurements. Higher CO and NO_X emissions were observed for the larger engine sizes compared to the smaller ones. The third evolved objective of the study was:

to simulate the real-world driving cycle using VISSIM and emission estimation.

Micro-simulation software VISSIM 5.10 was utilised to model the motorcycle driving cycle of motorcycles along a short section of AQMA (the same section was used for onboard emissions measurement). Motorcycle manoeuvres differ from those of other vehicles in the following ways, other vehicles follow one after another while motorcycle movement is two-dimensional, (longitudinal and lateral movement). Such types of driving behaviour are modelled in VISSIM using the Weidmann approach of 1974. The

‘Wiedemann’ approach model consists of: (1) Vehicle Following Behaviour (2) Lane Change (3) Lateral Behaviour and (4) Signal Control.

The above objectives were met by preparing input data for VISSIM, altering the driver behaviour for the motorcycle driving cycle and simulation modelling using several combinations of input parameters. The outputs were assessed visually using a graphical plot then calibrated and statistically validated using the GEH values. From the results, the speed pattern of the simulated driving cycle was found to be concentrated in the range of 0-10 km h^{-1} and 10-30 km h^{-1}. This range was found to be lower than EMDC values. The average speed over the whole driving cycle (V1) and the average running speed (V2) were found to be 14.4 km h^{-1} and 18.22 km h^{-1} respectively. Average acceleration and deceleration were 0.556 m/s^{-2} and 0.65 m/s^{-2} respectively. The mean length of simulated driving period was 1010 second (approximately 16 minutes), and the total driving length was 4.084 km (4.1 km). Time spent idling was about 18% of the total cycle time, which is much higher than that of the EMDC. The percentage of time spent in acceleration was found to be 24% as compared to 44.5 % in the EMDC. In contrast, the percentage of time spent in deceleration was 28% as compared to 46.87% in the EMDC. However, time spent in cruising for the simulated EMDC was found to be 29.45%, which is higher than the real world (7.24%). These differences were attributed to activation of the SCOOT system and average assignment of traffic flow on all the arms, and several assumptions, which were made in the simulated environment. The number of changes in acceleration and deceleration in one driving period in the simulation were found to be less than in real-world figures. Real-world driving cycles are sensitive to the traffic, SCOOT system signals, time of day, and other factors.

Due to time and resources limitations, only limited numbers of runs as well as a limited number of random seeds were implemented in the calibration and validation processes. The speed obtained from the simulated driving cycle was used for emission estimations using the NAEI emission coefficients. The average values of CO, HC and NO_X emissions (gm km^{-1}) for the 1000 cc engine were estimated to be 26.7, 1.72 and 0.283 respectively whereas CO, HC and NO_X emissions (gm km^{-1}) for the 600 cc were 10.581, 1.90 and 0.283 respectively. Finally, the last evolved objective of the study was

to validate and compare the emission factors obtained from onboard, laboratory and micro-simulation measurements.

At present, there are no site-specific emission factors of motorcycles for Edinburgh available from any sources. In this study, estimates of emission factors were made by using the three different approaches: (a) Onboard emission measurement; (b) Emission measurement in the lab using on chassis dynamometer and (c) Emission estimation using micro-simulation, which adopt the NAEI emission coefficients.

The emission factors (EFs) of CO and HC, which were obtained from the laboratory results, are higher based on EMDC. The emission factors which were calibrated from the laboratory results for the EMDC urban were much higher than standard regulatory emission factors, while the emission factors for the rural corridors were more similar to the standard ones (See Table 12.3).

EFs of CO pollutants, obtained from the lab and micro-simulation approach, did not show much compliance with current emission standards. In some cases, the emission factors exceeded the regulatory standards by more than 2100%. For example, CO (gm km^{-1}) deviates 2100% from the current Euro 3 standards for 1000 cc motorcycles. Higher percentages of differences of results were also observed for the WMTC and Euro 3 regulatory standards, since EF of these standards were stricter than Euro 1, Euro 2 and pre-Euro standards. Overall, the emission factors calibrated in the lab, which are based on EMDC, showed higher levels of CO, HC, and NOx emissions than the regulatory standards for motorcycles. In the case of the onboard measurement, emissions peaked at a number of points along the test corridor due to the higher percentage of acceleration and deceleration events at a number of intersection stops along the AQMA.

The emission factors, which are obtained from laboratory measurement for CO, HC, (for the EMDC) were much higher than those factors obtained from simulation (using NAEI). On the other hand, the emission factors obtained from simulation modelling were comparable to the results from the onboard measurements except for the NOx, which were higher for the onboard measurement than the simulation.

Finally, this study has enabled a better understanding of the relationship between driving cycles and emissions. This study has been successfully used to calibrate the Edinburgh motorcycle driving cycle (EMDC) and to adapt emission estimation approaches using laboratory onboard and simulation modelling techniques.

13.3 Recommendations for future research

Driving cycle and emission

1. Increase the sample size for the driving cycle estimation and emission estimates. This includes increase in number of motorcycles, number and types of routes, number of runs, number of drivers, motorcycles type based on engine size, model year.
2. The impact of motorcycle engine temperature on emissions and fuel consumption needs further research.
3. The influence of gear change strategies on emissions still needs evaluation to derive a more representative driving cycle.
4. Investigation of the impact of all the above factors on further pollutants such as particulate matters and VOCs, under different weather, seasonal, and road conditions can be extended for further research..
5. There is a lack of software, which could be used to evaluate the alternative emission scenarios. In this case, development of user-friendly graphical interface (GUI), which can facilitate data input and allow the development of alternative emission scenarios through a 'what if' scenario (WIS) generator is very urgent.

Micro simulation

6. While micro simulation is being widely used in a large number of transport applications, the results obtained from the micro simulation modelling should be used with care. Further investigations of micro-simulation modelling in the area of driving behaviours are needed. Additional micro-simulation runs should be made to investigate the impact of changes to the number of variables (e.g. speed,

traffic, engine size, signal time and random seeds). Other vehicles and traffic parameters can be calibrated at a more detailed level (e.g. road types.)

From this study, it was found that the driving cycle of motorcycles significantly differs from that of cars. Because the way motorcycles move is not the same as cars, which usually follow one after another along traffic lanes (i.e. mainly the longitudinal manoeuvres are the most important criteria for modelling any sizable vehicles' behaviour). On the other hand, because of their characteristics, the movement of motorcycles is two-dimensional with longitudinal and lateral movements. The longitudinal movement contributes to forward movement and lateral movements are used to take up appropriate positions across the lane. Motorcycles can get longitudinal gap to accelerate their speed by lateral movements for overtaking. Therefore, vehicular dynamic characteristics such as speed, acceleration, deceleration, cruise and idling also change.

Motorcycles have the ability to move parallel to queue, filter into the traffic through narrow gaps and at intersections to move ahead of the queues. Therefore, vehicle-operating modes of the motorcycles are significantly different from those of cars, and hence this will impact upon emission models, which will also differ.

While modelling driving cycles through micro simulation procedure, special care should be taken regarding assumptions made for driving behaviour parameters including input variables. For example during the course of this research work, driving behaviour parameters in the VISSIM model were modified to reflect motorcycle characteristics. These include look-ahead distance, number of observed vehicles, waiting time before diffusion, desired position of free flow (right, left or any) and allowing overtaking on the same lane. The motorcyclist aggressive speeds have also been replicated into VISSIM, after consideration of the published literature and carrying out a number of trial runs. Further research investigations should be done to determine suitable values of these parameters under various conditions and their impacts on driving behaviour parameters. For example, changes in the proportion of motorcycles, size of traffic, lane width and creating special lanes for motorcycles.

Moreover, most of the available micro-simulation models have been mainly developed with the car in mind (mostly adopting the car following model principles). While changing values of the parameters in these models to represent characteristics of the motorcycles might achieve improved results, there will also be other parameters and variables specifically relevant to motorcycles, which are not included at all in the model. These variables, such as engine size, catalytic converters, engine power and motorcycles engine technologies will no doubt affect the quality of the results. Further investigations into the appropriateness of different models to different conditions should be carried out.

There is a need for detailed investigations of driving cycles in any local condition. Since driving cycles are affected by several parameters such as road geometry, speed limit, signal pattern, traffic fleet, and driver behaviour, it is not feasible for a driving cycle developed in one area to be applicable at another area, even with some similar characteristics.

Health Impact

7. The impact of motorcycle exhaust emissions on public health needs to be further investigated for the UK and Scotland, and the external costs to the society should be further assessed.

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Appendix 5.1

Review of different micro simulation models

Review of different micro simulation model

1. Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN 2)

AIMSUN 2 was used in a pilot study of traffic management schemes on an environmental cell of the city of Dublin, measured flows and speeds were used as calibration variables. The Center for Transportation Studies of the University of Minnesota used AIMSUN2 in a simulation study of the I-494 freeway in Minneapolis; again AIMSUN2 was validated and calibrated against the flow and speed values provided by the detectors on the freeway. A large AIMSUN2 hybrid model of urban freeways and service roads consisting of the Barcelona's Ring Roads and main accesses to the city has been validated and calibrated using the observed flows and speeds. Quite recently, the Dutch company DHV, users of AIMSUN2 have conducted several simulation studies in some Dutch cities (Maastrich, The Hague, Eindhoven, etc.) in which accurate calibrations of the models have been conducted against real-world data. Also the Saudi consultant company Beeah of Riyadh has used calibrated models of AIMSUN2 in its analysis of the transportation conditions during the pilgrimage to Mecca. Codina and Garica (2004) extended the traditional microscopic simulation paradigm in which, instead of a pure stochastic emulation of traffic flows on a road network. Vehicles are assigned to paths from origins to destinations according to stochastic route choice models. This extension was a fundamental requirement to properly evaluate by simulation especially intelligent transport systems. They also contributed for methodology for the analysis of traffic scenarios for conflicting situations. This methodology implemented in a new software platform AIMSUN/ISM, has two modules. Application of AIMSUN/ISM and testing as part of the ISM (Intermodal Strategy Manager) project, in the framework of the WAYFLOW Program was done in Hessen, Germany.

2. CORSIM

Corridor Simulation (CORSIM) is a microsimulation program developed by the FHWA (FHWA, 2005). It is a program that has evolved over time from two separate traffic simulation programs. The first program, NETSIM or TRAF-NETSIM, is an arterial analysis program that models arterials with at grade intersections. The second program, FRESIM, is a freeway model that models uninterrupted facilities including grade separated expressways and interstate freeways. CORSIM combined these two programs in order to have the ability to analyze complete systems. The effects of traffic operations between freeways and signalized ramp terminal intersections can be analyzed directly as opposed to analyzing the two facility types and “guessing” the potential impacts one type of facility has on the other. One advantage of the CORSIM software is that it has been refined based on input from a number of different users from around the country. As a result of all the inputs various problems have been identified and corrected (Advance CORSIM Training Manual, 2005).

3. DRACULA

It has been tested on a number of SATURN networks and some travel performance such as delays and speed are compared with those from the calibrated SATURN models. Further calibration is expected to be carried out in the next few months in two projects involving traffic management measures for kerb guided bus and park & ride schemes.

4. NEMIS

It has been used to test strategies in five European cities (Turin, Alessandria, Salerno, Gothenburg and Leeds). The data required for calibration is the following: travel times on routes, queue lengths at the end of red stages, flows. The accuracy of the model has been demonstrated by the results of field trials in Turin, Salerno and Gothenburg. SITRA-B: Car-following rule partially validated (travel times were checked on an 8-intersection axis. Calibrated on a Lyon sub-network (LLAMD project). Some checking / validation of parameters / behaviours can be achieved through the visualisation interface facilities.

5. ARTEMiS

ARTEMiS (Analysis of Road Traffic and Evaulation by Micro-simulation previously called SITRAS) is another microscopic (time interval update) simulation model being developed by University of New South Wales since 1995. Hidas (2005) modelled vehicle interactions in microscopic simulation of merging and weaving using ARTEMiS traffic simulators. Based on the video recording, on the microscopic details of merging and weaving manoeuvres under congested traffic conditions, traffic manoeuvres were classified into free, forced and cooperative lane changes. A new lane change model was developed incorporating explicit modelling of vehicle interaction.

6. SISTM

SImulation of Strategies for Traffic on Motorways (SISTM) has been designed to study motorway traffic in congested conditions with the aim of developing and evaluating different strategies for reducing congestion (Fox, 2005). The program is available from Transport Research Laboratory (TRL) in UK, or the Highway Agency, SISTM can assess different motorway layouts (i.e., junction designs), variable speed limit systems ramp metering systems, modified vehicle characteristics, modified driver behaviour. It has been developed for the UK Highways Agencies, but is available to anyone requiring the modeling of motorways. It is a microscopic motorway simulation with a car following algorithm that uses a modified Gipps' equation. Driver behaviour is described by two parameters; aggressiveness and awareness; these are used to produce distributions of desired speed and indirectly desired headway.

7. *VISUM*

VISUM uses the travel demand data and the supply data to evaluate the transportation system. Three different impact models are available to the users: simulation of the behaviour of public transport passengers, the operator model that determines the operational indicators of a public transport service and an environmental impact model that assesses the impact of the transportation system on the environment. While VISUM is not widely used as a travel demand modelling tool in the United States, it provides an interface to other commonly used travel demand modelling tools such as EMME\2 and TranPlan. Moreover, VISUM provides users with a COM interface that can be used to develop external scripts to read data or attributes from other programs. This feature is very valuable, especially when local transportation agencies use other travel demand modelling tools. In addition, VISUM can export data to as well as import data from VISSIM (described above).

Simulation software was developed by the Group Research Department of VOLKSWAGEN AG and the PTV system GmbH (Fellendorf, 1999). Five separate models were integrated in one software suite to cover traffic demand, route choice, traffic flow, traffic-induced emissions and air quality. The traffic demand model followed a behaviour-oriented disaggregated approach. The dynamic route choice was calculated by an iterated simulation of the entire day. Each individual vehicle travelled through the road network using a microscopic traffic flow model. Fuel consumption and exhaust gas emissions of all vehicles in the network were determined based on dynamic characteristics of the TÜV Rheinland. A new microscopic approach was presented which includes cold start and warm-up induced extra emissions that contain a thermodynamic part model for engines and catalytic converters, improving accuracy in comparison to previously known calculation methods. The air quality was calculated with a microscopic flow and dispersion model considering the 3-D structure of built-up-areas. Typical applications of this simulation software extended from traffic and air quality-oriented assessment of isolated intersections up to optimising the entire road network of cities. In our study, initially our network was coded in VISSIM 4.20 for a limited size of 1500m, while our actual network was 4.1km. VISUM was used to rescale that network in actual size because it generates nodes and links available in the VISSIM network.

Appendix 6.1

Specification and accuracy of measurement of Performance Box

Appendix: 6.1

Specification and accuracy of measurement of Performance Box

GPS

Velocity		**Distance**	
Accuracy	0.2 Km/h	Accuracy	0.05% (<50 cm per Km)
Units	Km/h or Mph	Units	Metres / Feet
Update rate	10 Hz	Update rate	10 Hz
Maximum velocity	1000 Mph	Resolution	1 cm
Minimum velocity	0.1 Km/h	Height accuracy	10 metres 95% CEP**
Resolution	0.01 Km/h		
Absolute Positioning		**Time**	
Accuracy	2.5m 95% CEP**	Resolution	0.1 s
Update rate	10 Hz	Accuracy	0.1 s
Resolution	1 cm		
Heading		**Power**	
Resolution	0.01°	Input voltage range	6 – 28 V DC
Accuracy	0.2°	Current	Typically 100 mA
Acceleration		**Environmental and Physical**	
Accuracy	1%	Weight	225 grams
Maximum	4 G	Size	113 mm x 63 mm x 93 mm
Resolution	0.01 G	Operating temperature	-20°C to +50°C
Update rate	10 Hz	Storage temperature	-30°C to +80°C
Memory		**Definitions**	
Type	SD Card	** CEP = Circle of Error Probable	
Recording time	Dependent on card capacity*	95% CEP (Circle Error Probable) means that 95% of the time the position readings will fall within a circle of the stated diameter	

** Approximately 1.1Mb per hour used*

(Source: Performance Box User Guide, 2007)

Appendix 6.2

Motorcycle emission questionnaire

TOM GRAISGE

(5)

Motorcycle Emissions Research Questionnaire

NAPIER UNIVERSITY EDINBURGH

TRI

The purpose of this questionnaire is to obtain data for an PhD research project at Napier University. All responses will be confidential to the researcher. Please complete **all** questions in Section

0071 22104(1/2/3)(1/2/3/4) 3

Section A: **Questions Relating to Your Motorcycle** *(Please Tick one a on each line as appropriate or wrtie appropriate)*

Do you have MotorBike ✓ Scooter Moped Other

Engine Type 2- Stroke 4-Stroke ✓

Technlogy Type
- With improved oxidation catalyst
- Port fuel Injection with oxidation ca ✓
- Port fuel injection with 3 -way catalyst
- Air assisted direct fuel injection with 3 way catalyst
- Without oxidation catalyst
- No idea about type of technlogy

Engine Size (as 50CC, 125CC, 650 CC) 794 *(in cubic cm)*

Name of the manufacturer (Like Honda, BMW, Kawasaki, Suzuki etc) HONDA

Year of manufacture (in year as 2001, 2002 , 2004, 2006) 1998

Average weight of vehicle (***in Kg*** **)** 200

Approximately Average Annual Mileage (*mile*) 10,000

Average distance travelled per litre *(in mile*) Or mile/gallan Urban Area Rural Motorway Other

AVERAGE 55 mpg

Usual Journey purpose Work Related ✓ Personal/Liesure ✓ Other *(Please Specify)*

When buying a new motorcycle which *one* of the following chracteristics would you consider as the most important (Rate 1, 2, 3, 4, 5, 6) ? or You can tic more than one

Engine Size	4	Make/Model	1
Emission rate	5	Colour	6
Fuel Consumption	2	Price	3
		Other *(Please Specify)*	

When approaching a red traffic light do you coast (engage the clutch) or do you use the engine braking (gear down) when slowing down ?

Coast Engine ✓ Unsure

Which class of road takes up most of your driving ?

Urban Rural ✓ Motorway Other *(Please Specify)*

How often do you go for routine maintenace of your vehicle ?

Three time in year Two time in year ✓ Once in a year Once in two year Never Other *(Please Specify)*

When driving along a clear straight road in a 30mph zone which gear would you normally use ?

2nd 3rd 4th ✓ 5th 6th Unsure

Section B: **Information About Yourself** *(Please Tick one a on each line as appropriate)*

Gender Male ✓ Female

Age 17-24 25-35 36-45 ✓ 46-55 56+

Occupation LECTURER

No. of years driving licence held 25

Annual Household Income Up to £10k £11-£20k £21-30k £31-£39k ✓ £40k+

Section C:	Questions Relating to Routes of travelling by Motorcycle*(Please Tick __one__ a on __each__ line as appropriate or wrtie approprirate)*

Name of the Routes (from and To)

From	BIGGAR	To	EDINBURGH
From	BIGGAR	To	TWEEDSMUIR (A701)
From	WISTON	To	EDINBURGH

Average distance betwween start and end of routes in miles 37

Number of traffic light in between routes 7

Average Speed Limit on Roads*(like 20mph, 30mph, 60mph, etc)*

From	60/30	To	
From	60	To	
From	60/30	To	

Number of lanes (1, 2, 3, 4)

From	1	To	
From	1	To	
From	1	To	

Time of driving (AM/PM) From Home 7:15am From office 5:00pm

Is there any public transport bus sharing the roads on your travelled routes (in percentage share) Yes ✓ No Both

very poor service

Type of driving level you will preferred if opted for driving , please circle)

Urban (0-30mph)		**Rural (0-60mph for single lane , 0--70mph for dual length)**		**Motorway(0-70mph)**		**Other**	
	Low Speed(0-5 Kmph)		Low Speed(0-15 Kmph)		Low Speed(0-15 Kmph)		Speed(0-15 Kmph)
	Medium Speed (5-10 Kmph)		Medium Speed (15-30 Kmph)		Medium Speed (15-30 Kmph)		Medium Speed (15-30 Kmph)
	High Speed(10-20 Kmph)		High Speed(30-45 Kmph)		High Speed(30-45 Kmph)		High Speed(30-45 Kmph)
	Very High Speed (20-30 Kmph)		Very High Speed (>45 Kmph)		Very High Speed (>45 Kmph)		Very High Speed

Please indicate if you would be willing to take part in a further experiment, which will last for 5 test run between your home to work place trips, where you will drive through an area of Edinburgh/outskirt, in order to test motorcycle emission levels. If you preferred, and also you will be entered to a draw of 20 £ gift voucher for M&S for your time.

yes

If you have any feedback or queries relating to this survey or any of it's questions, and would like to contact the researcher, please do so by contacting Mr Ravindra Kumar r.kumar@napier.ac.uk, Dr Wafaa Saleh by email at w.saleh@napier.ac.uk,

Please complete the information below if you would be willing to partake in a further experiment, otherwise leave blank and thank you for taking the time to completing this questionnaire

Name: THOMAS GRASSIE **Contact Number:** 07902261642

Home Postcode: ML12 6HT **Email Address:** t.grassie@napier.ac.uk

Motorcycle Emissions Research Questionnaire NAPIER UNIVERSITY EDINBURGH TRI Transport Research Institute

Mark the tentative driving routes for morning(by firm line) /evening by dotted line

Appendix 7.1

Base Summary data of driving cycle

Appendix: 7.1

Base Summary data of driving cycle

Route 001: Napier University to Fife								
Date	**01/08/2007**	**16/08/2007**	**16/08/2007**	**21/08/2007**	**22/08/2007**	**22/08/2007**	**23/08/2007**	**Total Length(m)**
Time of travel	AM	AM	AM	AM	AM	AM Off Peak	PM Off Peak	
Routes Types	M	M	M	M	M	M	M	
Engine types CC	1000	1000	1000	1000	1000	1000	1000	
Age of the driver	46	46	46	46	46	46	46	
Average annual mileage(km)	11200	11200	11200	11200	11200	11200	11200	
Total driving length(M)	*17889.23847*	*17889.23847*	*17893.41278*	*16074.13194*	*31772.66111*	*31772.6611*	*29343.07958*	***162634.4235***
Date	**01/08/2007**	**16/08/2007**	**16/08/2007**	**21/08/2007**	**22/08/2007**	**22/08/2007**	**23/08/2007**	
Time of travel	AM	AM	AM	AM	AM	AM Off Peak	PM Off Peak	
Routes Types	U	U	U	U	U	U	U	
Engine types CC	1000	1000	1000	1000	1000	1000	1000	
Age of the driver	46	46	46	46	46	46	46	
Average annual mileage(km)	11200	11200	11200	11200	11200	11200	11200	
Total driving length(M)	*9582.371667*	*5774.321944*	*9583.367222*	*4412.261806*	*10179.04389*	*9574.19972*	*5378.974583*	***54484.54083***

Appendix: 7.1

Route 002 : Napier to Linlithgow

Date	**01/08/2007**	**01/10/2007**	**02/10/2007**	**02/10/2007**	**03/10/2007**	**24/09/2007**	**25/09/2007**	
Time of travel	AM	PM	AM	PM	AM	AM	AM	
Routes Types	M	M	M	M	M	M	M	
Engine types CC	1000	1000	1000	1000	1000	1000	1000	
Age of the driver	45	45	45	45	45	45	45	
Average annual mileage	10000	10000	10000	10000	10000	10000	10000	
Average Routine Maintenance (yearly)	2	2	2	2	2	2	2	
Total driving length(M)	*672.9*	*28727.3936*	*21023.54819*	*31697.2775*	*29282.54444*	*28955.41597*	*21659.85194*	***162018.9***

Date	**01/08/2007**	**01/10/2007**	**02/10/2007**	**02/10/2007**	**03/10/2007**	**24/0910/2007**	**25/0910/2007**	
Time of travel	AM	PM	AM	PM	AM	AM	AM	
Routes Types	U	U	U	U	U	U	U	
Engine types CC	750	750	750	750	750	750	750	
Age of the driver	45	45	45	45	45	45	45	
Average annual mileage	10000	10000	10000	10000	10000	10000	10000	
Average Routine Maintenance (yearly)	2	2	2	2	2	2	2	
Total driving length(M)	*5129.0975*	*5891.04028*	*4518.478056*	*4772.636111*	*5921.358056*	*5984.058611*	*5984.058611*	***38200.73***

Route 003: Napier to Penicuik

Date	**12/10/2007**	**15/10/2007**	**16/10/2007**	**17/10/2007**	**18/10/2007**	**19/10/2007**		
Time of travel	AM	AM	AM	AM	AM	PM		
Routes Types	M	M	Rural	Rural	Rural	Rural		
Engine types CC	550	550	550	550	550	550		
Age of the driver	55	55	55	55	55	55		
Average annual mileage	10000	10000	10000	4000	4000	4000		
Average Routine Maintenance (yearly)	1	1	1	1	1	1		
Total driving length(M)	8581.64333	5609.670833	7780.922083	6765.48056	6730.710694	6797.6158	**42266.0433**	
Date	**12/10/2007**	**15/10/2007**	**16/10/2007**	**17/10/2007**	**19/10/2007**	**19/10/2007**	**19/10/2007**	
Time of travel	AM	AM	AM	AM	PM	**PM**	PM	
Routes Types	U	U	U	U	Rural	U		
Engine types CC	550	550	550	550	550	550	550	
Age of the driver	55	55	55	55	55	55	55	
Average annual mileage	10000	10000	10000	4000	4000	4000	4000	
Average Routine Maintenance (yearly)	1	1	1	1	1	1	1	
Total driving length(M)	8829.79681	8555.502778	4250.915139	3006.91847	20840.25208	3747.91403	5277.909167	**54509.20847**

Route 004 : Napier to Hoddington

Appendix: 7.1

Time of travel	PM off peak	PM off peak	AM	PM Off Peak	AM	PM off peak	AM	
Routes Types	U	U	U	U	U	U	U	
Engine types CC	650	650	650	5000	650	650	650	
Age of the driver	30	25	30	30	30	30	30	
Average annual mileage	5000	5000	5000	5000	5000	5000	5000	
Average Routine Maintenace (yearly)								
Total driving length(M)	*6467.122361*	*2622.17*	*4178.545695*	*6328.69653*	*12021.44347*	*13108.7267*	*6468.4525*	***51195.16***

Route : 005 Napier to Beggar

Date	**22/10/2007**	**23/10/2007**	**23/10/2007**	**24/10/2007**	
Time of travel	AM	AM	PM	AM	
Routes Types	U	M	M	M	
Engine types CC	794	794	1000	1000	
Age of the driver	45	45	45	45	
Average annual mileage	10000	10000	10000	10000	
Average Routine Maintenance (yearly)	2	2	2	2	
Total driving length(M)	*16256.57222*	*50267.55292*	*6165.851805*	*2213*	**74902.9769**

Date	**22/10/2007**	**22/10/2007**	**23/10/2007**	**23/10/2007**	**24/10/2007**	**24/10/2007**	**24/10/2007**	
Time of travel	AM	AM	AM	PM	AM	PM Off Peak	PM Off Peak	
Routes Types	U	U	U	U	U	U	U	
Engine types CC	794	794	794	784	1000	764	764	
Age of the driver	45	45	45	45	45	45	45	
Average annual mileage	10000	10000	10000	10000	10000	10000	10000	
Average Routine Maintenance (yearly)	2	2	2	2	2	2	2	
Total driving length(M)	*7412.569306*	*6134.376944*	*6141.477639*	*2326.04611*	*551.8*	*40179.99528*	*4098.48486*	***66844.75***

Appendix 7.2

Motorcycle driving cycle of Delhi (DMDC) and its comparison with Delhi motorcycle driving cycles

Appendix 7.2

Motorcycle driving cycle of Delhi (DMDC)

During the course of the current research, data collection for investigation of Delhi, motorcycle-driving cycle was carried out (Kumar et al., 2008; Saleh et al., 2009). Rapid increase of motorcycle ownership in Delhi has resulted in high pollution in road traffic as well as congestion in cities.

The vehicle population in Delhi is highest among all the metropolitan cities (Bombay, Calcutta, Delhi and Madras) in India. During 1985 to 2001, the total number has multiplied four times (CRRI, 2002). It is observed that the rate of growth of personal vehicles is higher than other types. The average annual growth rate of vehicles is about 19.7%. On average about 500 new vehicles are added in Delhi every day.

The main sources of air pollution in Delhi are buses, cars, auto-rickshaws, trucks and scooters/motorcycles. In 1993 there were about 47,800 cars/jeeps; 1,403,000 scooters/motorcycles; 11,400 taxis; 70,500 three-wheelers; 23,200 buses and 111,300 trucks. These data together indicates that about 2.1 and 3.6 million vehicles were active on the roads in Delhi during the period from 1993 to 2001 (http://www.delhimetrorail.com/corporates/ecofriendly/Chapter%201.pdf accessed on 25 May 2009). The details of these vehicles are given in Table A1. Of this traffic 65%, was comprised of motorcycles and scooters, showing that two-wheelers had the largest share of the total traffic fleet. Therefore, a case study was undertaken to investigate the driving cycle of motorcycles in Delhi. The length of driving data collection was around 8 km. The survey was conducted in April 2009 in Delhi city. The map of the typical study area is given in Figure A1.

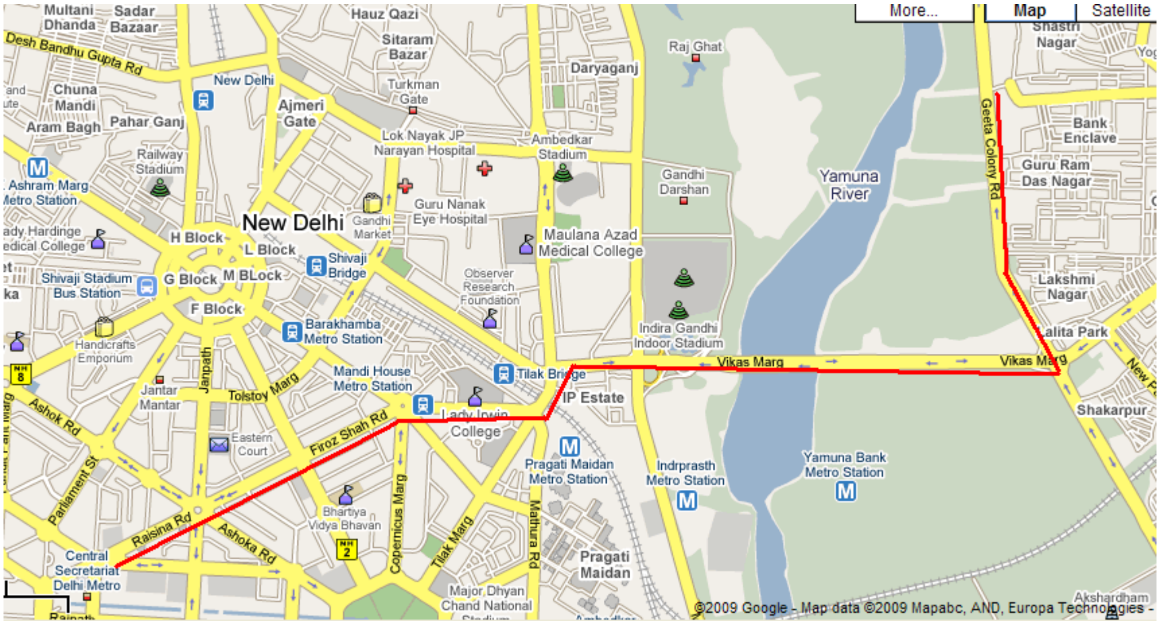


Figure A1 Map of Delhi study area of the selected route

Table A1 Details of traffic composition in Delhi (thousands)

Year	Car/Jeeps	Motor-cycle/Scooter	3-Wheeler	Taxi	Buses	Truck	Total
1985	1175	637	31	9	14	59	925
1986	8203	746	41	9	15	62	1076
1987	242	868	45	9	15	71	1250
1988	280	979	52	9	16	80	1416
1989	333	1083	58	9	17	90	1590
1990	384	1191	62	10	19	99	1765
1991	413	1253	65	10	20	102	1863
1992	440	1317	67	11	20	107	1962
1993	478	1403	70	11	23	111	2096
2001	957	2378	95	19	41	169	3658

(Source: Delhi Transport Authority)

Table A2 Comparison of assessment parameters of EMDC and DMDC

Assessment Parameter	Symbol	DMDC	EMDC
Average deceleration of all deceleration phases (m s^{-2})	d	0.90	2.59
Average acceleration of all acceleration phases (m s^{-2})	A	0.73	1.28
Average speed of entire driving cycle (km h^{-1})	V_1	34.36	33.50
Average running speed (km h^{-1})	V_2	36.61	38.85
Mean length of driving period (seconds)	C	847.80	769.63
Time proportion of driving modes in idling(fraction of time spent at speeds of (0-3 km h^{-1}) in %	Pi	1.04	1.51
Time proportion of driving in acceleration modes ($a > 0.1$ m s^{-2}) in %	Pa	46.83	44.45
Time proportion of driving in deceleration modes ($d < 0.1$ m s^{-2}) in %	Pd	42.73	46.87
Time proportion of driving modes in cruising modes ($a <= 0.1$ m s^{-2}, $d <= 0.1$ m s^{-2}) in %	Pc	9.44	7.24
Average number of acceleration and deceleration changes within one driving period	M	1667.00	1251.00
Root mean square acceleration	RMS		7.83
Positive kinetic energy (m s^{-2})	PKE	0.71	2.81
Total driving length (m)	L	8054.71	7313.59

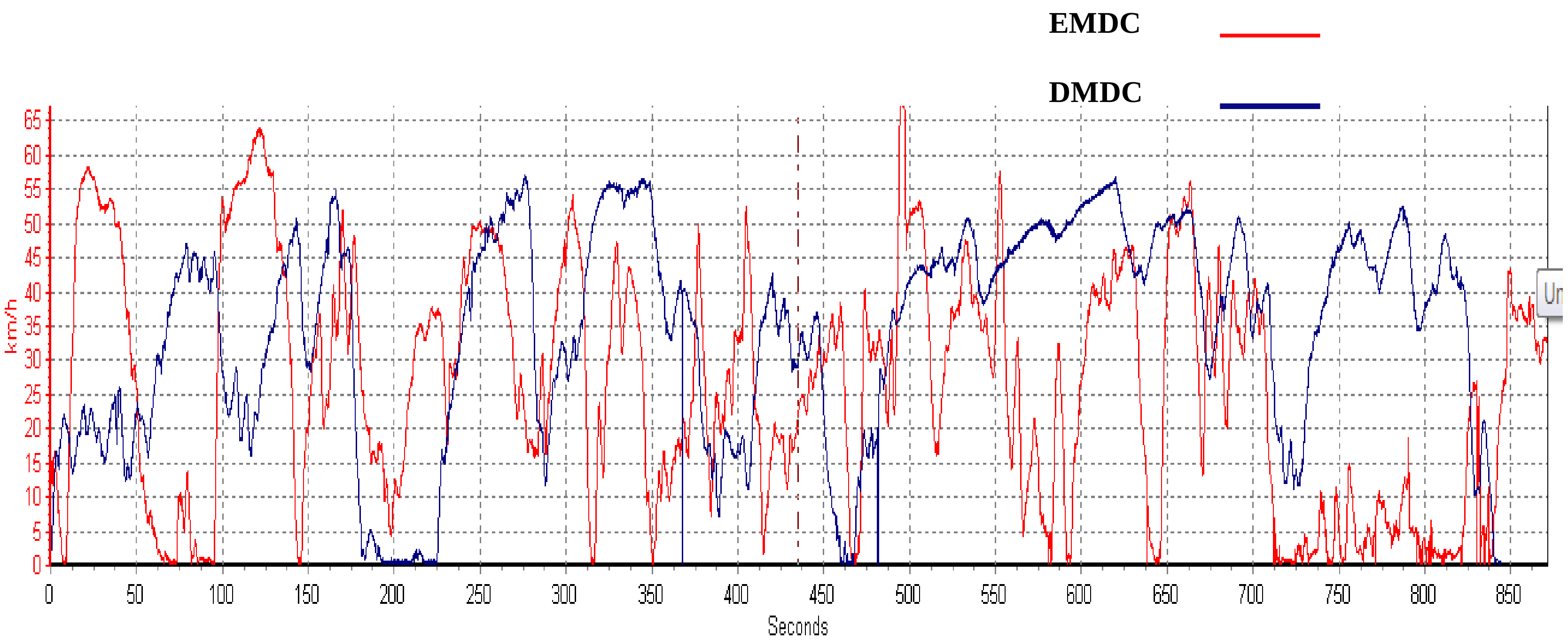


Figure A2Comparison of typical Delhi MDC and EMDC

Comparisons of motorcycle driving cycle of Delhi (DMDC) to EMDC

The maximum speed (70 km h^{-1}) attained by Edinburgh drivers exceeds the speed limit (30mph=48 km h^{-1}) while Delhi motorcycle drivers never exceed 50 km h^{-1} (Figure A2). This indicates that while Delhi traffic has the same permitted speed limit (50 km $h^{-1)}$ drivers never exceed this limit, but in Edinburgh driving above the permitted limit is frequent (seen almost 8 times in this typical driving).

Acceleration and deceleration rates

Accelerations and deceleration rate was higher in EMDC (almost 2 to 3 times) compared to Delhi. The reason was quite clear: that the EMDC has motorcycles with higher engine sizes (>600 cc) than Delhi. Although average running speeds were almost same, this reflects the similarity in driving speed and speed limits on Delhi roads (see Table A2).

Positive kinetic energy

Positive kinetic energy of EMDC was very high. This reflects the sport bike characteristic of Edinburgh as compared to Delhi motorcycles. In vehicle operation modes the percentage time spent in acceleration and deceleration modes of Edinburgh and Delhi were almost equal. Cruising time was found to be higher in Delhi motorcycle driving (Table A2).

Appendix 8.1

Measurement Principles of PMGA

Appendix 8.1

1. Measurement Principles of PMGA

The measurement principles of the PMGA are the same as those normally used in vehicle emission laboratories. Carbon dioxide (CO_2) and carbon monoxide (CO), hydrocarbons (HC) are measured by non-dispersive infrared principle (NDIR), and nitrogen oxides (NOx) by fuel cell sensor. Micro-gas gas analyser measure CO, Oxygen, with resolution 0.01%, while HC and NO with resolution of 0.1% resolution. The following are interesting features of the Probike MicroGas Analyser

- Totally portable. Accurate to International Organization of Legal Metrology (OIML).
- Operation via internal rechargeable battery or 12V adaptor.
- Lambda or Air/Fuel Ratio display.
- Print via optional infrared printer.
- RS232 port.
- Two minute warm up time.
- Automatic zero calibration.
- Low maintenance.
- Illuminated display.
- Oil & exhaust temperature sensors included.
- Ruggedly built with shockproof holster.
- British made.

The powerful microprocessor controlled circuit combined with advanced software allows up to 255 tests to be stored and printed as required. This is invaluable for comparing output from individual cylinders, or outputs before & after adjustment. The printouts can be customised to include company details and phone number together with the registration number for individual tests. Optional Windows software & connection cable allows the downloaded data from road tests to be analysed, displayed and saved (Probike Manual, 2008). The full kit includes the Micro Gas analyser, a foam-lined carry case, battery charger, 12V connection lead, RPM pickup; oil temp sensor, 4m hose, special M/C probe, 5 spare filters, manual.

2. Technical Specification of the PMGA

The technical specification of the PMGA is presented below in Table A1, which shows the accuracy, resolution of measurement, and other details.

Table A2 Technical specification of the Probike Micro Gas Analyser

Function	Range/value
Power supply	Internal rechargeable battery
Operation time	> 4 hours with pump on continuously
External power	12VDC or AC mains adapter
CO	0 - 10 % vol. (res: 0.01 %)
HC	0 - 10,000 ppm (res: 1ppm - 10 ppm above 2000)
CO2	0-16% (res: 0.1%)
O2	0-21% (res: 0.01%)
RPM	0-20,000
Temperature	0-200°C
Dimension (LWH) Approx.	220 x 55 x 120 mm
Net weight	1.0 kg
Warm-up time	2 minutes

The analyser was calibrated by service agent of PMGA before start of the test. Also we can do gas calibration verification by using the gas value on the calibration gas bottle in house. The proper units of gas value should be taken care of while doing the calibration.

3. Lambda (λ)

The value of Lambda which is based on the ratio of air to fuel is a determinant for the burning efficiency of an engine. The value depends on the composition of the fuel, the air that is used for combustion and on the combustion products as found in the exhaust gases (see-equation A1.) take into account the fuel; carbon, hydrogen, oxygen, and water content, water contents of air, component of the exhaust gases (carbon dioxide and carbon monoxide, hydrocarbon and nitrogen dioxides.

$$\lambda = \frac{CO_2 + (CO/2) + O_2 + [H_{CV}/4x\{3.5 + CO/CO_2)\} - Ocv/2]x(CO_2 + CO)}{(1 + H_{CV}/4 - O_{cv}/2)x\{(CO_2 + CO) + (K_1 xHC)}$$

………equation A1

Which is based on measurement of CO, CO2, HC and O2.

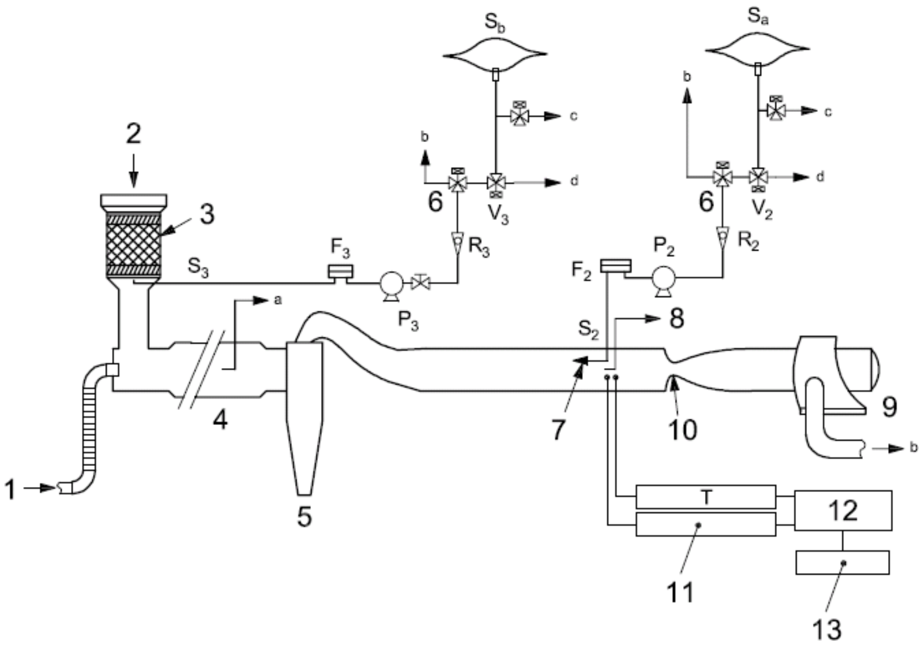
4. Air fuel ratio

Air fuel ratio is another method for displaying the burning efficiency of an engine. The calculation for the AFR is Lambda multiplied by 14.7 for petrol and 15.6 for LPG (typically).

Appendix 8.2

Schematic diagram for the representative closed type CVS system with CFV

Schematic diagram for the representative closed type CVS system with CFV



1. Exhaust gas
2. Dilution air
3. Dilution air filter
4. Mixing chamber
5. Cyclone
6. Diversion valve
7. Sampling venture
8. Continuous sampling probe
9. Blower
10. Main critical flow venturimeter.
11. Pressure gauge
12. Calculator
13. Integrator

F2, F3 filters, P2, P3 pumps, R2, R3 flow meters, Sa, Sb sampling bags S2, S3 probes V2, V3 valves T temperature gauge a To HFID special sampling line when HFID is used.
b To atmosphere c To exhaust pump d To analysing system.

Appendix 8.3

Laboratory testing on chassis dynamometer test setup in University of Graz

Appendix 8.3

Laboratory testing on chassis dynamometer test setup in University of Graz

a. Online data monitoring

b. Cooling of engine by air fan

c. Chassis Dynamometer and motorcycle

Appendix 9.1
Detailed summary of On-board emission measurement

Appendix 9.1

Detailed summary of onboard emission

Sr.No	Test Date (date/month/year)	Time (am/pm)	Engine Size (cc)	Length Travelled (m)	Total Emission (gm/sec)			Emission (gm /km)			Pollutant Type	Driving mode* (gm/km)				Driving mode (% time spents)				Frequency of driving mode (sec)				Total journey time (minutes)	Average speed (km h-1)
					CO	**HC**	**NO_x**	**CO**	**HC**	**NO_x**		**D**	**I**	**C**	**A**	**D**	**I**	**C**	**A**	**D**	**I**	**C**	**A**		
1	25/02/2009	PM	1000	7680.52	14.76	0.27	0.08	1.89	0.03	0.01	CO	7.35	0.32	0.87	5.84	52.61	2.34	5.77	39.28	292.00	13.00	32.00	218.00	18.50	24.91
											HC	0.14	0.01	0.02	0.11										
											NO	0.04	0.00	0.00	0.03										
2	25/02/2009	PM	1000	7830.91	20.43	0.23	0.06	2.71	0.03	0.01	CO	10.10	0.06	0.58	8.74	47.58	2.77	7.61	42.04	275.00	16.00	44.00	243.00	19.27	24.39
											HC	0.12	0.01	0.00	0.10										
											NO	0.03	0.00	0.00	0.03										
3	26/02/2009	PM	1000	8033.00	16.13	0.20	0.04	4.02	0.05	0.01	CO	15.43	1.62	1.17	14.01	48.58	4.40	3.84	43.18	342.00	31.00	27.00	304.00	23.47	20.54
											HC	0.18	0.23	0.01	0.17										
											Nox	0.04	0.00	0.00	0.04										
4	26/02/2009	PM	1000	7988.95	28.55	0.34	0.08	3.57	0.04	0.01	CO	13.63	0.39	2.09	12.43	48.31	1.18	7.22	43.30	328.00	8.00	49.00	294.00	22.63	21.18
											HC	0.16	0.00	0.03	0.15										
											NO	0.04	0.03	0.00	0.04										
5	27/02/2009	PM	1000	7966.22	27.92	0.34	0.07	3.51	0.04	0.01	CO	13.86	0.90	1.67	11.49	49.14	3.28	6.08	41.50	315.00	21.00	39.00	266.00	21.37	22.37
											HC	0.17	0.01	0.02	0.14										
											NO	0.04	0.00	0.00	0.03										
6	27/02/2009	PM	1000	7969.52	22.99	0.27	0.07	2.89	0.03	0.01	CO	11.40	0.74	1.79	9.05	49.57	3.43	7.55	39.45	289.00	20.00	44.00	230.00	19.43	24.61
											HC	0.14	0.01	0.02	0.11										
											NO	0.03	0.00	0.00	0.03										
7	06/03/2009	AM	1000	8056.00	22.60	0.25	0.05	2.81	0.03	0.01	CO	11.10	0.27	1.57	9.67	48.59	1.13	6.97	43.31	258.00	6.00	37.00	230.00	17.70	27.31
											HC	0.12	0.00	0.01	0.10										
											NO	0.03	0.00	0.00	0.02										
	Average			**7932.16**	**21.91**	**0.27**	**0.06**	**3.06**	**0.04**	**0.01**	**CO**	**11.84**	**0.61**	**1.39**	**10.18**	**49.20**	**2.65**	**6.43**	**41.72**	**299.86**	**16.43**	**38.86**	**255.00**	**20.34**	**23.61**
											HC	**0.15**	**0.04**	**0.02**	**0.12**										
	*** Where D-Deceleration, I-Idling, C-Cruising, A-Acceleration**										**NO**	**0.03**	**0.01**	**0.00**	**0.03**										

Appendix 9.1

Detailed summary of onboard emission

Sr.No	Test Date (date/month/year)	Time (am/pm)	Engine Size(cc)	Length Travelled (m)	Total Emission (gm/sec)			Emission (gm / km)			Pollutant Type	Driving mode (gm/km)				Driving mode (% time spents)				Frequency of driving mode (sec)				Total journey time (minutes)	Average speed (km h-1)
					CO	**HC**	**NO_x**	**CO**	**HC**	**NO_x**		**D**	**I**	**C**	**A**	**D**	**I**	**C**	**A**	**D**	**I**	**C**	**A**		
8	12/03/2009	PM	600	8119.47	12.40	0.31	0.03	1.53	0.04	0.00	CO	20.88	0.36	0.79	6.36	45.27	3.20	5.68	45.85	311.00	22.00	39.00	315.00	22.90	21.27
											HC	0.35	0.03	0.02	0.23										
											Nox	0.02	0.00	0.00	0.01										
9	12/03/2009	PM	600	7976.56	13.82	0.36	0.04	1.74	0.04	0.00	CO	7.10	0.29	0.93	5.50	50.18	2.21	5.88	41.73	273.00	12.00	32.00	227.00	18.13	26.39
											HC	0.17	0.01	0.02	0.15										
											NO	0.02	0.00	0.00	0.01										
10	13/03/2009	AM	600	8013.08	16.33	0.36	0.04	2.04	0.05	0.00	CO	7.73	0.38	1.08	7.14	49.03	2.48	6.19	42.30	277.00	14.00	35.00	239.00	21.63	22.52
											HC	0.18	0.01	0.02	0.15										
											NO	0.02	0.00	0.00	0.02										
	Average			**8036.37**	**14.19**	**0.34**	**0.04**	**1.77**	**0.04**	**0.00**	**CO**	**11.90**	**0.34**	**0.93**	**6.33**	**48.16**	**2.63**	**5.92**	**43.29**	**287.00**	**16.00**	**35.33**	**260.33**	**20.89**	**23.40**
											HC	**0.23**	**0.02**	**0.02**	**0.18**										
	*** Where D-Deceleration, I-Idling, C-Cruising, A-Acceleration**										**NO**	**0.02**	**0.00**	**0.00**	**0.01**										

Appendix 9.2

Detailed summary of laboratory measurement

Emission test according to
Directive 2003/77/EC of 18.08.06 amending
Directive 97/24/EG chap. 5, annex II

Univ.-Prof. Dipl.-Ing. Dr. H. Eichlseder
Institute for
Internal Combustion Engines Thermodynamics
TU-Graz

Vehicle Manufacturer:	Honda	Date:	02.02.2009
Type:	CBR600F	Expert opinion-No.:	090402-1/1/1-1/HJS
Displacement[cm^3]:	599		
Engine power [kW]:	- @ -- U/min	Test-No.:	1
Working Cycles:	4	Tester:	Schacht
Chassis.-Nr.:	JH2PC35G92M302631	Driver:	Tretter
Engine.-Nr.:	-	Remarks:	
Milage Reading [km]:	11,565		

Ref. Weight [kg]:	280	Equival.Mass [kg]:	280	Tire Pressure [bar]:	3
C [N/(km/h)^2]:	0,0242	A [N]:	24,6		

gear shift points:	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
up shift at [km/h]:	20	40	60	80	
down shift at [km/h]:	15	30	60	80	

Exhaust Gas Limits: Euro III

TYP I	CO [g/km]:	2	HC [g/km]:	0,3	NOx [g/km]: 0,15

Analyse Test TYP I	Abgas	Verdünnungsluft
HC [ppm]	492,000	9,000
CO [ppm]	1566,000	3,000
CO_2 [Vol-%]	0,756	0,045
NOx [ppm]	9,700	0,000

Air Pressure [hPa]:	979,1	Humidity [%]:	31	Temp. [°C]:	22,4
Distance [km]:	12,98	Volume [m^3]:	105,566	Consum.[g]:	

Emissionen
Test Typ I:

CO [g/km]	15,892	794,583	% from limit
HC [g/km]	2,434	811,444	% from limit
NOx [g/km]	0,137	91,571	% from limit
CO_2 [g/km]	113,972		

Analyse Test TYP II:

CO [%]	1,14
CO_2 [%]	8,53
Idle speed [rpm]	1000

Emissionen
Testtyp II:

CO_{corr} [%] (4Takt)	1,77

Carbon Balance:

mileage Test [km/l]	
mileage CB [km/l]	16,01
difference [%]	

Emission test according to
Directive 2003/77/EC of 18.08.06 amending
Directive 97/24/EG chap. 5, annex II

Univ.-Prof. Dipl.-Ing. Dr. H. Eichlseder
Institute for
Internal Combustion Engines Thermodynamics
TU-Graz

Vehicle Manufacturer:	Kawasaki	Date:	23.03.2009
Type:	Z1000E	Expert opinion-No.:	090323-1/1/1-1/HJS
Displacement[cm^3]:	1015		
Engine power [kW]:	- @ -- U/min	Test-No.:	1
Working Cycles:	4	Tester:	Schacht
Chassis.-Nr.:	KZT00E-002492	Driver:	Tretter
Engine.-Nr.:	-	Remarks:	
Milage Reading [km]:	~50.000		

Ref. Weight [kg]:	360	Equival.Mass [kg]:	350	Tire Pressure [bar]:	3
C [N/(km/h)^2]:	0,0254	A [N]:	31,7		

gear shift points:	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
up shift at [km/h]:	20	40	60	80	
down shift at [km/h]:	15	30	60	80	

Exhaust Gas Limits: Euro III

TYP I — CO [g/km]: 2 — HC [g/km]: 0,3 — NOx [g/km]: 0,15

Analyse Test TYP I	Abgas	Verdünnungsluft
HC [ppm]	566,000	8,000
CO [ppm]	3362,000	3,000
CO_2 [Vol-%]	0,687	0,042
NOx [ppm]	13,500	0,000

Air Pressure [hPa]:	962,4	Humidity [%]:	28	Temp. [°C]:	22,5
Distance [km]:	12,95	Volume [m^3]:	105,495	Consum.[g]:	

Emissionen
Test Typ I:

CO [g/km]	34,206	1710,317	% from limit
HC [g/km]	2,816	938,765	% from limit
NOx [g/km]	0,189	126,230	% from limit
CO_2 [g/km]	103,587		

Analyse Test TYP II:

CO [%]	1,00
CO_2 [%]	11,8
Idle speed [rpm]	1050

Emissionen
Testtyp II:

CO_{corr} [%] (4Takt)	1,17

Carbon Balance:

mileage Test [km/l]	
mileage CB [km/l]	14,12
difference [%]	

Vehicle Manufacturer:	Honda	Date:	03.04.2009
Type:	CBR600F	Expert opinion-No.:	090403-1/1/3-3/HJS
Displacement[cm^3]:	599		
Engine power [kW]:	- @ -- U/min	Test-No.:	1
Working Cycles:	4	Tester:	Schacht
Chassis.-Nr.:	JH2PC35G92M302631	Driver:	Tretter
Engine.-Nr.:	-	Remarks:	EMDC cumulated
Milage Reading [km]:	11,607		

Ref. Weight [kg]:	280	Equival.Mass [kg]:	280	Tire Pressure [bar]:	3
C [N/(km/h)^2]:	0,0242	24,6	31,7		

gear shift points:	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
up shift at [km/h]:	20	40	60	80	
down shift at [km/h]:	15	30	60	80	

Air Pressure [hPa]: 980,5 Humidity [%]: 28 Temp. [°C]: 22,1

URBAN Distance [km]: 5,86 Volume [m^3]: 47,226

Emissions

Test Typ I:

		[g]
CO [g/km]	13,119	76,88
HC [g/km]	4,372	25,62
NOx [g/km]	0,207	1,21
CO_2 [g/km]	115,161	674,84

RURAL Distance [km]: 8,87 Volume [m^3]: 49,126

Emissions

Test Typ I:

		[g]
CO [g/km]	9,431	55,26
HC [g/km]	1,558	9,13
NOx [g/km]	0,138	0,81
CO_2 [g/km]	93,745	549,35

EMDC cumulated Distance [km]: 14,73 Volume [m^3]: 96,352

		[g]
CO [g/km]	8,971	132,14
HC [g/km]	2,359	34,75
NOx [g/km]	0,137	2,02
CO_2 [g/km]	83,108	1224,19

mileage CB [km/l] Urban: 15,69
Rural: 20,69

Vehicle Manufacturer:	Kawasaki	Date:	24.03.2009
Type:	Z1000E	Expert opinion-No.:	090324-1/1/3-3/HJS
Displacement[cm^3]:	1015		
Engine power [kW]:	- @ -- U/min	Test-No.:	1
Working Cycles:	4	Tester:	Schacht
Chassis.-Nr.:	KZT00E-002492	Driver:	Tretter
Engine.-Nr.:	-	Remarks:	EMDC cumulated
Milage Reading [km]:	~50.000		

Ref. Weight [kg]: 360 | Equival.Mass [kg]: 350 | Tire Pressure [bar]: 3

C [$N/(km/h)^2$]: 0,0254 | A [N]: 31,7

gear shift points:	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
up shift at [km/h]:	20	40	60	80	
down shift at [km/h]:	15	30	60	80	

Air Pressure [hPa]: 956,7 | Humidity [%]: 28 | Temp. [°C]: 22,5

URBAN Distance [km]: 5,84 | Volume [m^3]: 47,186

Emissions

Test Typ I:

		[g]
CO [g/km]	44,109	257,60
HC [g/km]	3,654	21,34
NOx [g/km]	0,263	1,54
CO_2 [g/km]	109,295	638,28

RURAL Distance [km]: 8,82 | Volume [m^3]: 49,304

Emissions

Test Typ I:

		[g]
CO [g/km]	36,932	215,68
HC [g/km]	1,498	8,75
NOx [g/km]	0,142	0,83
CO_2 [g/km]	78,483	458,34

EMDC cumulated Distance [km]: 14,66 | Volume [m^3]: 96,49

		[g]
CO [g/km]	32,284	473,28
HC [g/km]	2,052	30,09
NOx [g/km]	0,161	2,36
CO_2 [g/km]	74,804	1096,62

mileage CB [km/l]

Urban: 12,35

Rural: 16,62

Trade name: HONDA CBR600F **Production number :** JH2PC35G92M302631

Date: 2009-04-02 **Place of the test:** TU Graz **Name of recorder:** Schacht

Climate: **Atmospheric pressure:** 9,798 kPa **Atmosph. temperature:** 295 °K

Motorcycle Class	Reduced speed Yes/No	Cycle part	Starting cond.	Test number	Distance driven in km	Emmision in g				Fuel cons. In litre
						HC	CO	NOx	CO_2	
1,2 or 3	No	1	Cold	1	4,09	12,408	40,845	0,604	499,23	-
				2						
				3						
				Average	4,09	12,408	40,845	0,604	499,23	-
1		1	Hot	1						
				2						
				3						
				Average						
2 or 3	No	2	Hot	1	9,13	17,777	161,112	1,322	771,55	-
				2						
				3						
				Average	9,13	17,777	161,112	1,322	771,55	-
3	No	3	Hot	1	15,75	33,0241	549,334	3,1469	1137,7	-
				2						
				3						
				Average	15,75	33,0241	549,334	3,1469	1137,7	-

Motorcycle Class	Reduced speed Yes/No	Cycle part	Starting cond.	Weighting in per cent	Emmision in g/km				Fuel cons. in litre/100km
					HC	CO	NOx	CO_2	
1		1	Cold	50					
		1	Hot	50					
		-		Final Result					
2		1	Cold	30					
		2	Hot	70					
		-		Final Result					
3	No	1	Cold	25	3,03	9,99	0,15	122,06	-
	No	2	Hot	50	1,95	17,65	0,14	84,51	-
	No	3	Hot	25	2,10	34,88	0,20	72,23	-
	-	-	-	Final Result	2,26	20,04	0,16	90,83	-

	HC	CO	NOx
limit	0,1	2,62	0,17
% of limit	2256,1%	764,9%	93,7%

Trade name: Kawasaki Z1000E **Production number :** KZT00E-002492

Date: 2009-03-03 **Place of the test:** TU Graz **Name of recorder:** Schacht

Climate: **Atmospheric pressure:** 9,630 kPa **Atmosph. temperature:** 296 °K

Motorcycle Class	Reduced speed Yes/No	Cycle part	Starting cond.	Test number	Distance driven in km	Emmision in g				Fuel cons. In litre
						HC	CO	NOx	CO_2	
1,2 or 3	No	1	Cold	1	4,10	12,480	150,998	0,570	528,21	-
				2						
				3						
				Average	4,10	12,480	150,998	0,570	528,21	-
1		1	Hot	1						
				2						
				3						
				Average						
2 or 3	No	2	Hot	1	9,08	15,962	392,214	1,470	686,63	-
				2						
				3						
				Average	9,08	15,962	392,214	1,470	686,63	-
3	No	3	Hot	1	15,69	19,292	596,319	8,7702	1433,2	-
				2						
				3						
				Average	15,69	19,292	596,319	8,7702	1433,2	-

Motorcycle Class	Reduced speed Yes/No	Cycle part	Starting cond.	Weighting in per cent	Emmision in g/km				Fuel cons. in litre/100km
					HC	CO	NOx	CO_2	
1		1	Cold	50					
		1	Hot	50					
		-		Final Result					
2		1	Cold	30					
		2	Hot	70					
		-		Final Result					
3	No	1	Cold	25	3,04	36,83	0,14	128,83	-
	No	2	Hot	50	1,76	43,20	0,16	75,62	-
	No	3	Hot	25	1,23	38,01	0,56	91,35	-
	-	-	-	Final Result	1,95	40,31	0,26	92,85	-

	HC	CO	NOx
limit	0,1	2,62	0,17
% of limit	1947,3%	1538,4%	150,3%

Appendix 9.3

Example of emission model for CO, HC and NOx of motorcycles with respect to time spent in different vehicle operating model for Edinburgh

The emission models as well as the respective R^2 values for CO HC and NO_X (all gm sec^{-1}) are developed as shown in Figure A1 –A12 and complied in Table A1. Although R^2 values are not great, the approach clearly presents a potential directive for the estimation and assessment of emissions and driving cycles. It should be noted here that these equations are calibrated based on pooled data of two motorcycles. It would be possible to develop a strong empirical relationship by including more engine sizes and number of parameters. These models were developed based on limited data set for two motorcycle engine sizes 600 and 1000cc of motorcycles and adopted by Andre (2009), Rapone (2005), and Frey (2001) to obtain emission rates for cars in Europe.

where:

Ta = % time spent in acceleration

Td = % time spent in deceleration

Ti = % time spent in idling

Tc = % time spent in cruising.

This can be used to assess the vehicle renewal policy of the Edinburgh motorcycle fleet once accurate emission has been estimated.

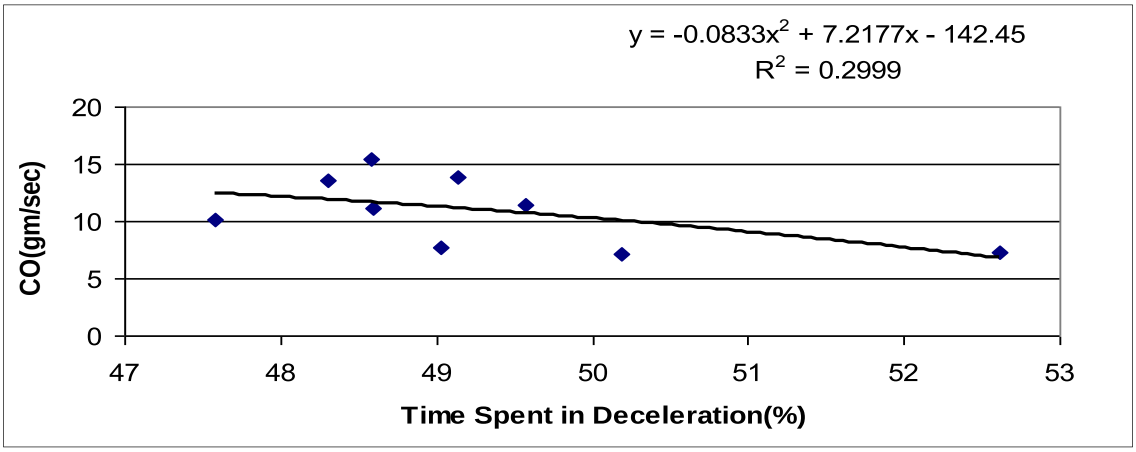


Figure A1 Correlation between times spent in deceleration modes and CO emission factor

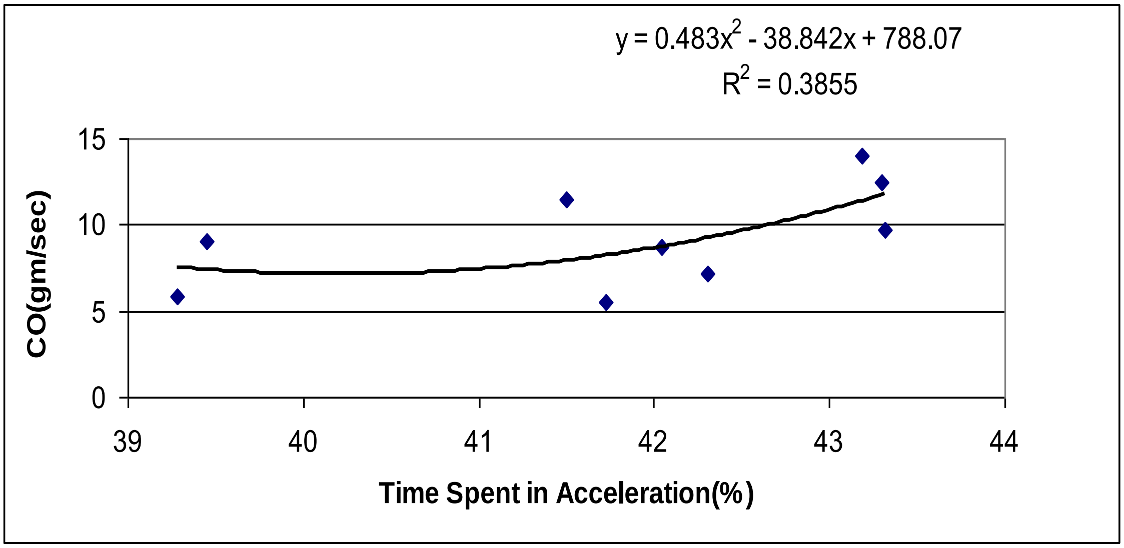


Figure A2 Correlation between time spent in aeceleration modes &CO emission factor

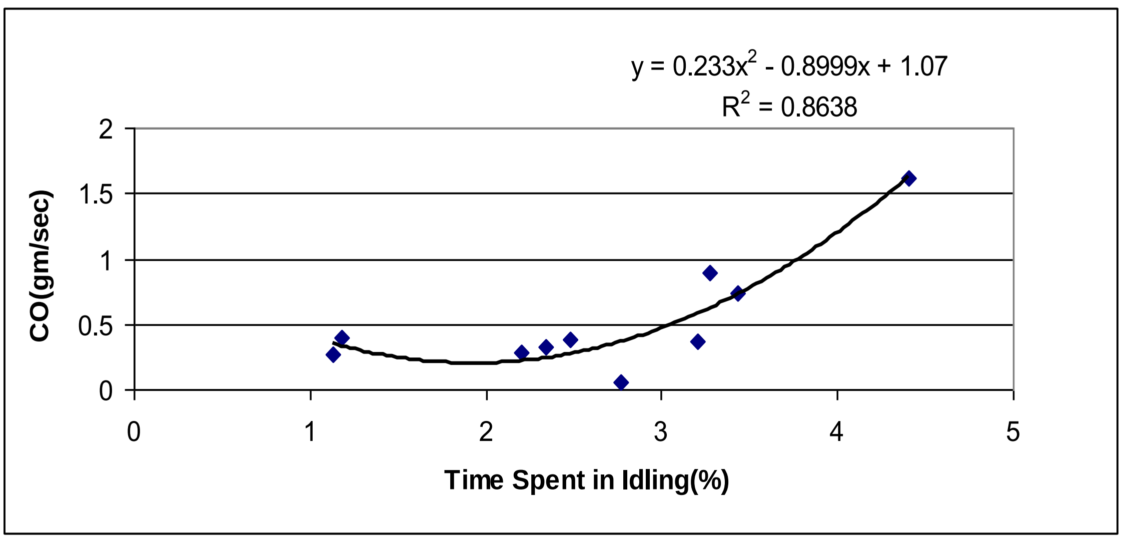


Figure A3 Correlation between time spent in idling modes & CO emission factor

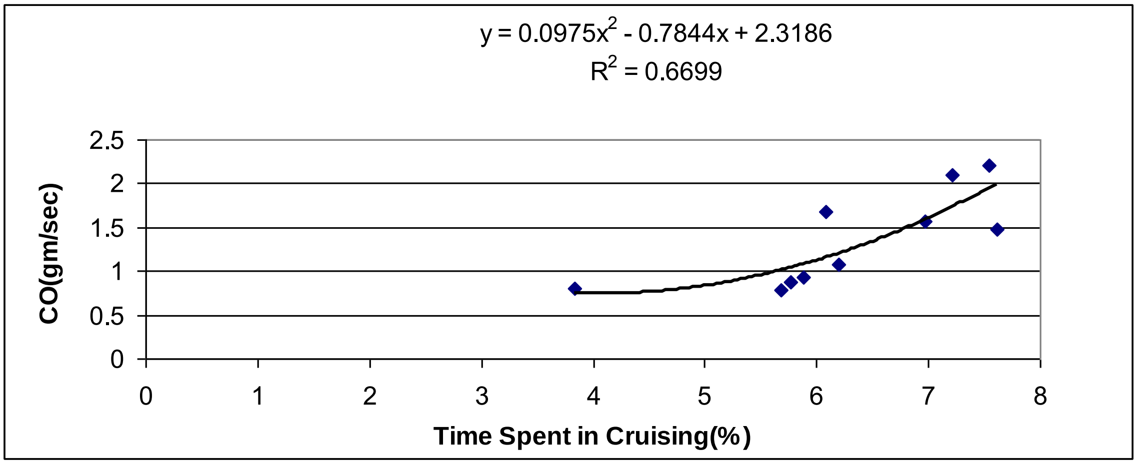


Figure A4 Correlation between time spent in cruising mode & CO emission factor

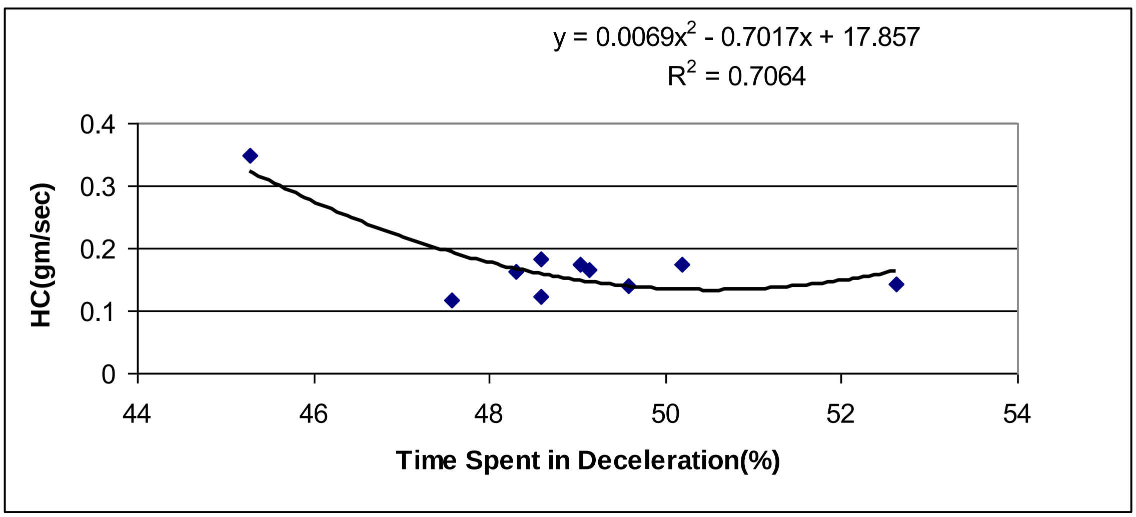


Figure A5 Correlation between time spent in deceleration modes & HC emission factor

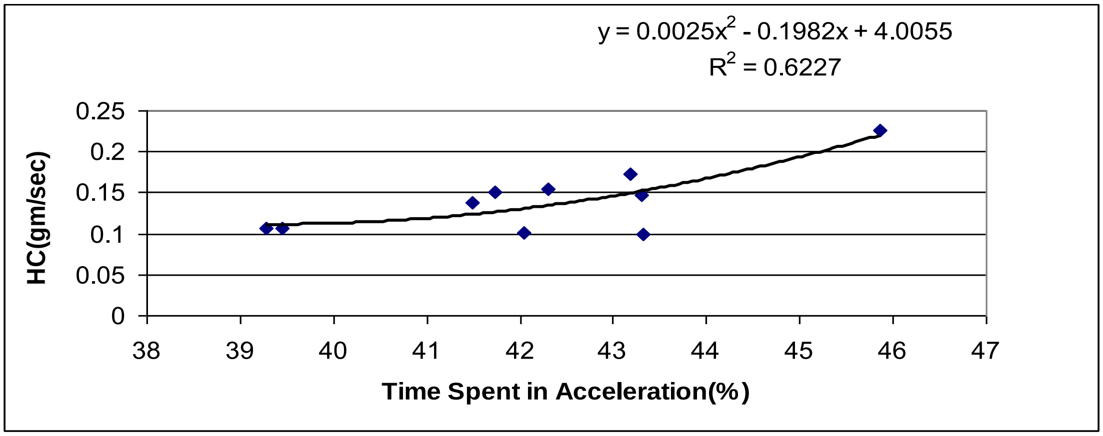


Figure A6 Correlation between time spent in acceleration modes & HC emission factor

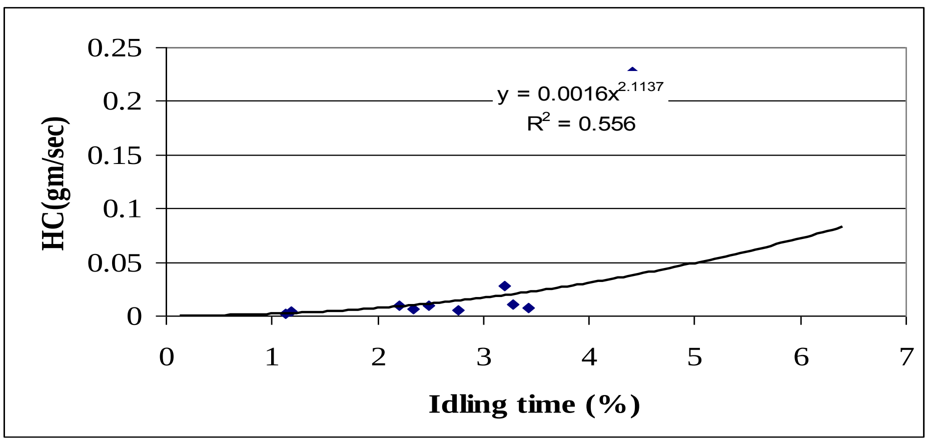


Figure A7 Correlation between time spent in idling modes & HC emission factor

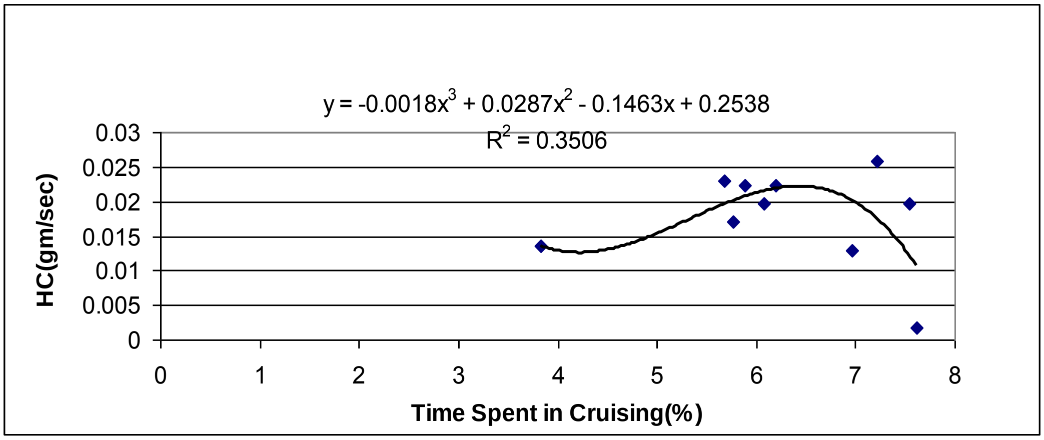


Figure A8 Correlation between time spent in cruising modes & HC emission factor

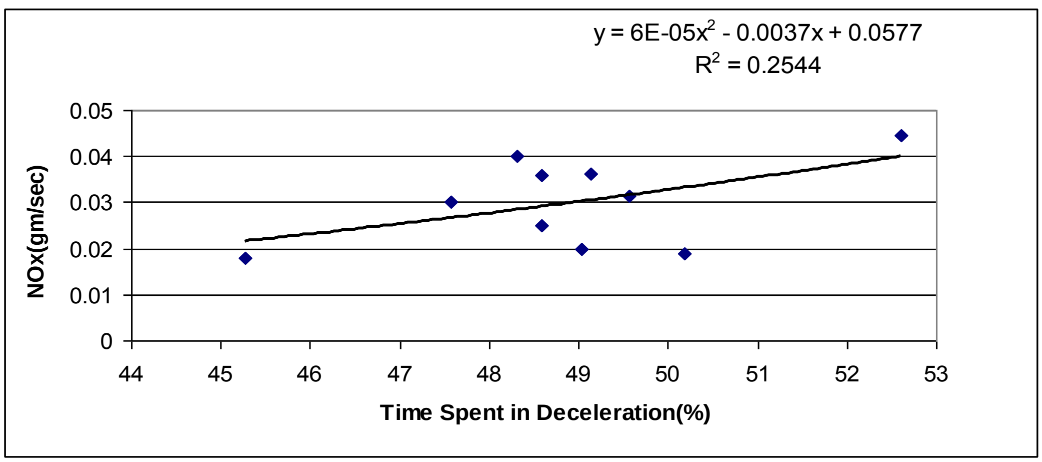


Figure A9 Correlation between time spent in deceleration modes & NO_X emission factor

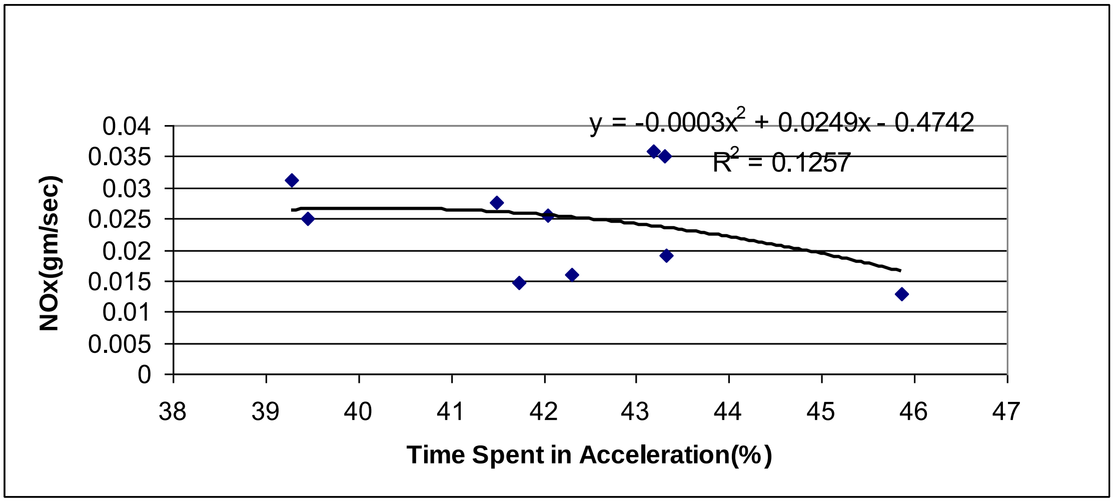


Figure A10 Correlation between time spent in acceleration modes & NO_X emission factor

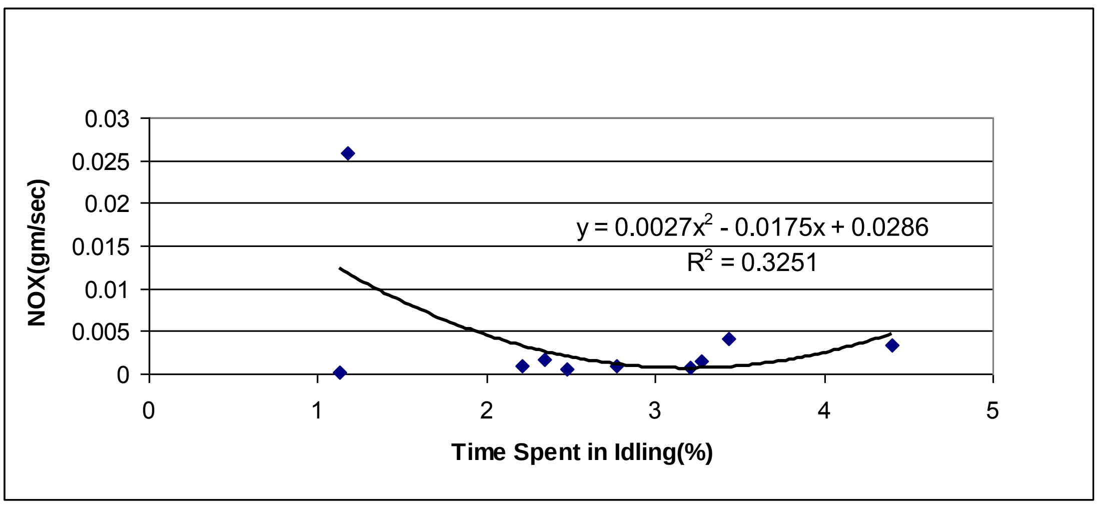


Figure A11 Correlation between time spent in idling modes &NO_X emission factor

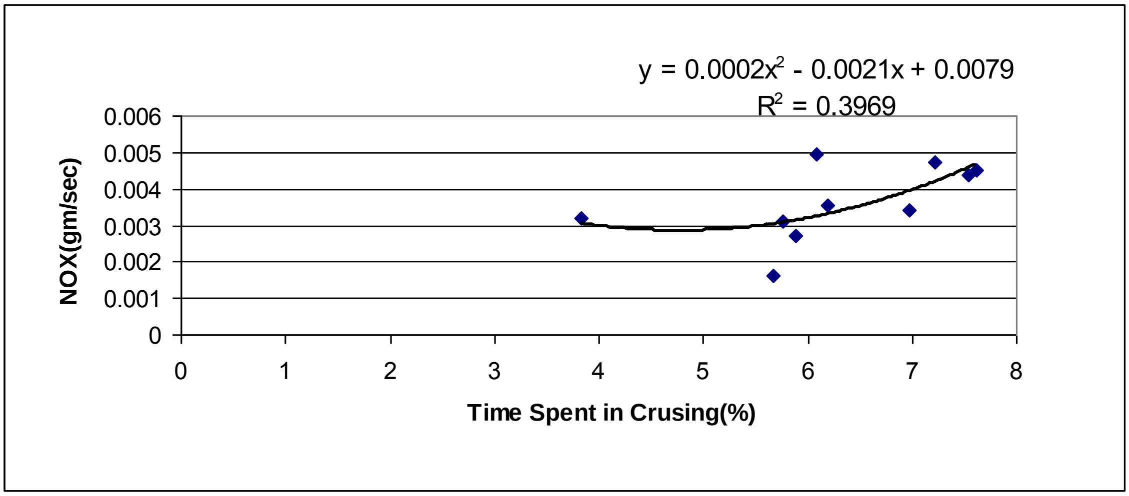


Figure A12 Correlation between times spent in cruising & NO_X emission factor

Table A1: Modal emissions model and time spent in different driving models

Pollutant total emission	Driving modes	Model	R^2	Application Range(%)
CO (g/sec)	Deceleration	$-0.0833*T_d^2+7.2177*T_d-142.45$	0.299	47.5-52.8
	Acceleration	$0.483*Ta^2-38.84*Ta+788.07$	0.385	39.5-43.5
	Idling	$0.233*Ti^2-0.899*Ti+1.07$	0.863	1-4.5
	Cruising	$0.0975*Tc^2-0.7844*Tc+2.3186$	0.670	4.0-7.0
HC (g/sec)	Deceleration	$-0.0069*T_d^2-0.701*T_{d+}17.857$	0.706	47.5-52.8
	Acceleration	$0.0025*Ta^2-0.1982*Ta+4.0055$	0.627	39.5-43.5
	Idling	$0.0016*Ti^2+2.1137$	0.556	1-4.5
	Cruising	$-0.0018*Tc^3-0.0287*Tc^2-0.1436*Tc+0.2538$	0.350	4.0-7.0
NOx (g/sec)	Deceleration	$0.00006*T_d^2-0.0037*T_d+0.0577$	0.254	47.5-52.8
	Acceleration	$-0.0003*Ta^2+0.0249*Ta-0.4742$	0.125	39.5-43.5
	Idling	$0.002*Ti^2-0.0175*T_i$	0.325	1-4.5
	Cruising	$0.0002*Tc^2-0.0021*Tc+0.0079$	0.397	4.0-7.0

Appendix 10.1

Camera Specification

Specification of Camera

Items	Specification
Number of effective pixels	8.2 million pixels
CCD sensor	1/2.5-inch CCD
Storage media	Internal memory (Approx. 12 MB) / xD-Picture CardTM (16MB-2GB) /
File format	JPEG (Exif Ver 2.2)
Lens	Fujinon 3x Optical zoom lens, F2.8 - F5.2
Lens focal length	f=6.2mm - 18.6mm, Equivalent to 38 - 113mm on a 35mm camera
Focus distance	Normal: Approx. 40cm / 1.3 ft to infinity Macro: Wide angle: Approx. 15cm / 6 in. to infinity Telephoto: Approx. 40cm / 1.3 ft to infinity
Shutter speed	8 sec. to 1/1500 sec. (depends on exposure)
Aperture	Wide Angle: F2.8 - F5.2
Sensitivity	Auto / Equivalent to ISO 64 /100 / 200 / 400 / 800 / 1600 (Standard Output Sensitivity)
Exposure modes	Programmed AE
White balance	Automatic scene recognition. Preset (Fine, Shade, Fluorescent light (Daylight), Fluorescent light (Warm White), Fluorescent light (Cool White), Incandescent light)
LCD Monitor	2.5-inch, approx. 153,000 pixels, Amorphous Silicon TFT colour LCD monitor, approx. 96% coverage
Self-timer	Approx. 10 sec./2 sec. delay
Video Output	NTSC / PAL selectable
Digital Interface	USB High-speed
Power source	Rechargeable NP-45 Li-ion battery (included)
Dimensions	91 (W) x 55 (H) x 19 (D) mm / 3.8 (W) x 2.2 (H) x 0.75 (D) in.
Weight	Approx. 110g / 4.3 oz. (excluding accessories, batteries and memory card)
Digital Zoom	Approx 5.1x
Shooting modes	Mode dial: Auto, Baby, Picture Stabilisation, Red-eye Reduction, Digital ZOOM, Portrait, SP (Scene Position), Movie. SP: Landscape, Sport, Night, Natural light, Beach, Snow, Fireworks, Sunset, Flower, Party, Museum, Text, Manual
Movie recording	640 x 320, 320 x 240 pixels, 30 frames/sec. with monaural sound. Zoom function cannot be used during movie recording.
Playback	Slide show, Trimming, Single frame, Multi-frame playback, sorting by date, Image Rotate.

Appendix 10.2

Details of data collection periods of intersections across the selected corridor

Appendix10.2

Details of data collection periods of intersection across the selected corridor

Sr.no	Date	Time	Name of Junction	Type of Junction	Number of Lane	Other Characteristic
1	12/8/2008	PM	Charlotte-Square-Princess Street	T	2	No Right turn (RT) from East End
2	1/07/2008 30/6/2008 12/9/2008	AM/PM	Charlotte Sqaure –Albany Place	T	2	
3	12/9/2008	PM Off Peak	Charlotte Sqaure –St George Street	T	2	
4	01/07/2008	PM	Morningside Colinton Road	4	2	
5	01/9/2008 30/6/2008	PM Peak/off Peak	East-West Fountain Bridge	4 Arms	2	No RT from East End
6	09/08/2008 04/08/2008 01/7/2008 2/7/2008	PM off Peak/Peak	Elder Street-York Street-Queen Street	T	3	
7	12/8/2008 12/09/2008 30/6/2008	PM Off Peak/Peak	Fedric Street-Queen Street	4	2	
8	11/7/2008 12/9/2008 26/6/2008	PM Off Peak/Peak	Gilmore Place-Travit Street	4	2	
9	26/9/2008	PM off Peak/Peak	Hanover Street-St Dunda Street	4	2	
10	18/9/2008	PM Off Peak	Leamingston_Terrace-Bruntsfield	4	2	
11	25/06/2008	PM peak/off Peak	Merchiston-Bruntsfield	T	2	No Signal
12	27/06/2008 27/8/2008 28/8/2008 19/6/2008	PM AM off Peak	Morrison_bred-Street_lothian Road	4	2	
13	03/07/2008	PM Off	New Castle Street-Queen Street	4	2	

	04/08/2008 30/06/2008	Peak/Peak				
14	08/08/2008 09/08/2008	PMOff Peak/Peak	St Andrew Street-Queen Street	4	2	
15	03/07/2008 09/08/2008 04/08/2008	PM Off Peak	St David Street-Queen Street	4	2	
16	12/09/2008	PM Off Peak	South Charlotte Square between-George Square	3	2	
17	12/08/2009	PM off peak	Shandwick Place Lothian Road	3	2	
18	03/07/2008 11/07/2008 04/08/2008	PM Off Peak	Toll Cross Road	5	2	
19	12/09/2008	PM Off Peak	Viewforth_Forbes_bruntsfield	4	2	
20	28/8/2008	PM Off Peak	West Approach Road_Lothian Road	4	2	
21	03/07/2008 08/08/2008 01/07/2008	PM Off Peak	York Place_Broughton Street	4	2/1	

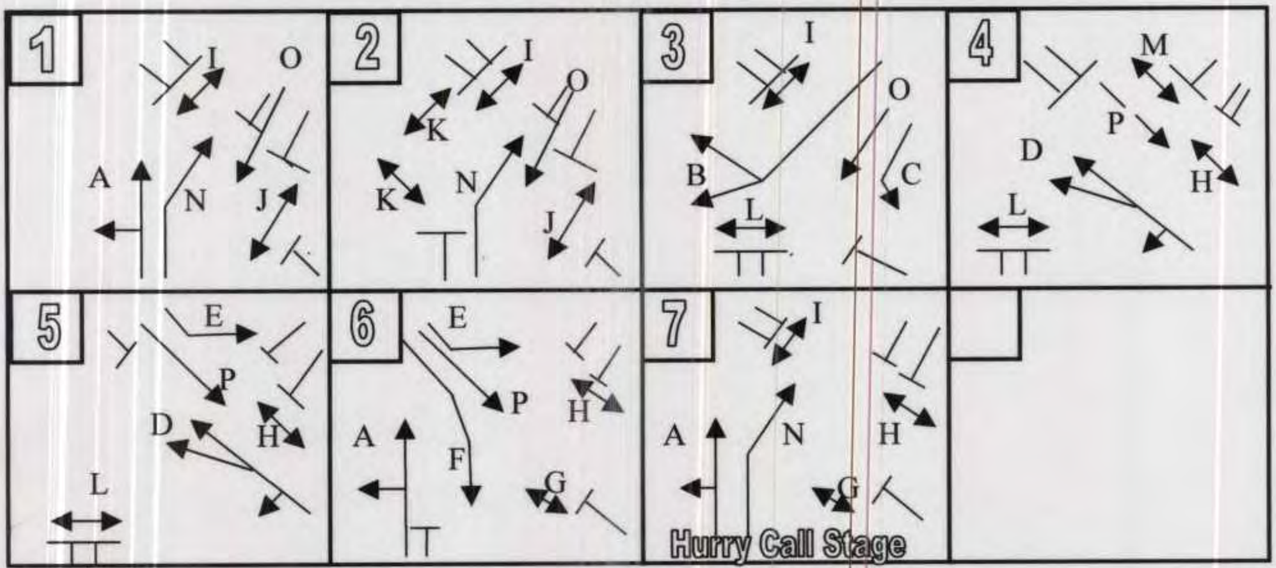
Appendix 10.3

Example of Edinburgh city council data for stage sequence, method of control, conflict table

Name of Intersection : Toll Cross

No: 16

STAGE SEQUENCE:



INTERGREEN TABLE:

TO PHASE

FROM PHASE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
A		5		5							7	5				
B	5			5	5	5					8		5	5		5
C					5			5		5				5		5
D	7	5				5	5			5	9			5	5	
E		5	7						5	8			6	5	7	
F		5		5					5			7		5		
G				5											5	
H			5												5	
I					6	6										6
J			8	8	5											5
K	5	5		5												
L	8					5								8		
M		6			5									5		
N		6	8	5	5	5						5	8			5
O				5	5		7	5								5
P		5	5						5	5				5	5	

CITY OF EDINBURGH
CITY DEVELOPMENT
TRAFFIC SIGNALS QA
JOB NUMBER
REVISION NUMBER: B
AUTHORISED BY (INITS): aw
DATE: 21/5/03

Name of Intersection : Toll Cross

16

Date 21/5/03

Stages		Phase	Location	Det No.	Max Greens A	B	C	D	Min	Ext
	1	A	Home St ahead and left		24				7	1.0
		N	Home St right turn		20				7	3.0
		O	Lauriston Pl ahead						7	
		I	Earl Grey St east Peds						7	
		J	Brougham St Peds						9	
	2	N	Home St right turn		20				7	3.0
		O	Lauriston Pl ahead						7	
		I	Earl Grey St east Peds						7	
		J	Brougham St Peds						9	
		K	Earl Grey + Wst Tollx Peds						6	
	3	B	Lauriston Place Right Turn		12				7	1.0
		C	Lauriston Place Left Turn		12				7	1.0
		O	Lauriston Pl ahead						7	
		I	Earl Grey St east Peds						7	
		L	Home St west Peds						12	
	4	D	Brougham Street		8				8	1.0
		P	Earl Grey St ahead arrow						4	
		H	Lauriston Pl Sth. Peds						6	
		L	Home St west Peds						12	
		M	Lauriston Pl Nth. Peds						7	
	5	D	Brougham Street		8				8	1.0
		E	Earl Grey St ahead and left		16				7	1.0
		P	Earl Grey St ahead arrow						4	
		H	Lauriston Pl Sth. Peds						6	
		L	Home St west Peds		24				12	1.0
	6	A	Home St ahead and left		24				7	1.0
		E	Earl Grey St ahead and left		16				7	1.0
		F	Earl Grey St right turn		16				7	1.0
		P	Earl Grey St ahead arrow						4	
		G	Home St east Peds						6	
		H	Lauriston Pl Sth. Peds						6	
	7	A	Home St ahead and left		24				7	1.0
		N	Home St right turn		20				7	3.0
		G	Home St east Peds						6	
		H	Lauriston Pl Sth. Peds						6	
		I	Earl Grey St east Peds						7	

Detection Port:____________

Name of Intersection : Toll Cross	No. 16

TIMETABLE EVENTS

Date: 21/5/03

No.	Day	Time	Function Required	Function Number	Plan/ Parameter
0	9	07:01:31	Introduce Plan	1	1
1	9	09:30:00	Introduce Plan	1	2
2	9	15:00:24	Introduce Plan	1	4
3	0	08:01:31	Introduce Plan	1	1
4	0	15:00:24	Introduce Plan	1	4
5	1	08:01:31	Introduce Plan	1	1
6	1	15:00:24	Introduce Plan	1	4
7	8	22:00:00	Isolate Controller	0	-
8	0	18:30:00	Introduce Plan	1	2
9	1	18:30:00	Isolate Controller	0	-

Function Numbers

0 = Isolate From CLF
1 = Introduce A CLF Plan
2 = Introduce A Parameter
(Combination of event switching)
3 = Selects An Individual Event Switch To Be Set
4 = Selects An Individual Event Switch To Be Cleared

Name of Intersection : Toll Cross

SITE NUMBER: 16 **DATE: 21/5/03**

PLI 0		INFLUENCE SET 0			
INF 0					
Group	Group	IFA		IFB	
No.	Time	Inf.	Stage	Inf.	Stage
0	23	1	1		
1	13	1	2		
2	14	1	3		
3	8	2	4		
4	10	1	5		
5	12	3	-		
6	20	1	6		
7					

PLI 1		INFLUENCE SET 1			
INF 1					
Group	Group	IFA		IFB	
No.	Time	Inf.	Stage	Inf.	Stage
0	27	1	1		
1	13	1	2		
2	15	1	3		
3	1	2	4		
4	26	1	5		
5	18	1	6		
6					
7					

PLI 2		INFLUENCE SET 2			
INF 2					
Group	Group	IFA		IFB	
No.	Time	Inf.	Stage	Inf.	Stage
0	18	1	1		
1	13	1	2		
2	18	1	3		
3	1	2	4		
4	25	1	5		
5	25	1	6		
6					
7					

PLI 4		INFLUENCE SET 4			
INF 4					
Group	Group	IFA		IFB	
No.	Time	Inf.	Stage	Inf.	Stage
0	13	1	1		
1	13	1	2		
2	15	1	3		
3	1	2	4		
4	26	1	5		
5	32	1	6		
6					
7					

GROUP INFLUENCES

0. Go To VA
1. Immediate Move To Stage ()
2. Demand Dependent Move To Stage ()
3. Hold
4. Prevent Moves Except To Stage ()
5. Add an immediate move to stage () to existing influence
6. Add a demand dependent move to stage () to existing influence.
7. Ignore - continue with previous influence (Parallel Stage Streaming)

Name of Intersection : Toll Cross

NO. 16

DATE: 21/5/03

PHASE DELAYS

DELAY NUMBER	ON CHANGE FROM STAGE	TO STAGE	DELAY PHASE	BY (SECONDS)
0	1	5	N	3
1	3	1	B	5
2	3	1	H	3
3	6	5	F	1
4	1	4	N	3
5	1	4	O	3
6	1	5	O	3
7	3	1	C	5
8	4	1	D	3
9	4	3	D	3
10	5	6	D	3
11	6	1	E	3
12	6	1	F	3
13	5	1	D	3
14	4	6	D	3
15	6	1	P	3
16	4	6	M	5
17	3	6	C	4
18	3	6	O	4
19	3	6	B	4
20	6	1	G	5
21	7	1	J	5
22	3	7	B	5
23	5	7	D	3
24	5	7	E	5
25	5	7	D	3
26	2	4	N	3
27	2	5	O	3
28	3	2	B	5
29	3	2	C	5

Appendix 10.4

Typical vehicle record output file from VISSIM

Appendix 10.4

```
TITLE "s1_rescaled_in_VISUM.net"
--------------------------------

-- VISSIM 5.10-04 [17010]

RANDOM_SEED         10
SIMULATION_DURATION  3600.0
SIMULATION_STARTTIME "00:00:00"
DATE             20083012
SIMULATION_SPEED MAX 1000.0
TIME_STEP           1
NUMBER_OF_CORES  MAX
UNIT             DISTANCE 1 0
UNIT             DISTANCE 2 0
UNIT             SPEED 0
UNIT             ACCELERATION 0
QUEUE SPEED UNDER 5.0  OVER 10.0 DX UNDER 20.0 LENGTH MAX 500.0
     FROM 0 UNTIL 99999  AGGREGATION_INTERVAL 99999

-- Multi-Run: --
----------------

MULTIRUN
     RANDOM_SEED            1
     RANDOM_SEED_INCREMENT  1
     NUMBER_RUNS            10
     DTA_INCREMENT          0.0
     EVAL_DIRECTORY "#data#"


-- Dynamic Assignment: --
-------------------------

DTA
     TRIP_CHAIN_FILE      1 "TC.fkt"
     MATRICES             0
     COST_FILE            "7.bew" NODE NO
     PATH_FILE            "7.weg" NODE YES
     COST_INTERVAL        1800
     MAX_PATHNUMBER       -999
     STRATEGY             0
     ROUTE_GUIDANCE_OFFSET 999999 999999
     OFFSET               0 0
     KIRCHHOFF_EXPONENT   3.50
     VOLUME     PERCENT   1.00
     PATHEVAL   PERCENT   -0.75
     DETOURS              2.50
     LOGIT                1.50000
     UNDER 0.00100
     RECTIFICATION
     VEHICLE_FILE
     CONVERGENCE
       PATHS         TRAVEL_TIME 0.15
       EDGE          TRAVEL_TIME 0.15   VOLUME 0.15
     MSA                  0
     ARCHIVE_FILES
```

```
-- Vehicle Types: --
```

Appendix 10.4

```
VEHICLE_TYPE  100
     NAME                 "Car"
     CATEGORY             CAR
     COLOR_DIST            1
     LENGTH               4.760
     WIDTH                1.500
     MASS                 1
     POWER                1
     LAYER                0
     KATTEMPERATURE       0
     WATERTEMPERATURE     0
     MAX_ACCELERATION     1
     DESIRED_ACCELERATION  1
     MAX_DECELERATION     1
     DESIRED_DECELERATION  1
     EQUIPMENT            NONE
     DRIVER               UNIDENTIFIED
     PASSENGERS           1.0
     VEHICLE_MODEL_DIST   10
     COST_COEFFICIENTS 1.000 0.000 1.000
     FEE 0.000 0.000 0.000 0.000
     ATTRACTION 0.000 0.000 0.000 0.000
     DESTINATION 0.000 0.000 0.000 0.000
     POSITION 0.000 0.000 0.000 0.000
     PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE  200
     NAME                 "HGV"
     CATEGORY             HGV
     COLOR_DIST            1
     LENGTH               10.215
     WIDTH                2.500
     MASS                 2
     POWER                2
     LAYER                0
     KATTEMPERATURE       0
     WATERTEMPERATURE     0
     MAX_ACCELERATION     2
     DESIRED_ACCELERATION  2
     MAX_DECELERATION     2
     DESIRED_DECELERATION  2
     EQUIPMENT            NONE
     DRIVER               UNIDENTIFIED
     PASSENGERS           1.0
     VEHICLE_MODEL_DIST   20
     COST_COEFFICIENTS 1.000 0.000 1.000
     FEE 0.000 0.000 0.000 0.000
     ATTRACTION 0.000 0.000 0.000 0.000
     DESTINATION 0.000 0.000 0.000 0.000
     POSITION 0.000 0.000 0.000 0.000
     PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE  300
     NAME                 "Bus"
     CATEGORY             BUS
     COLOR_DIST            1
     LENGTH               11.541
     WIDTH                2.500
     MASS                 3
```

```
      POWER                 3
     LAYER                 0
     KATTEMPERATURE        0
     WATERTEMPERATURE      0
     MAX_ACCELERATION      3
     DESIRED_ACCELERATION  3
     MAX_DECELERATION      3
     DESIRED_DECELERATION  3
     EQUIPMENT             NONE
     DRIVER                UNIDENTIFIED
     PASSENGERS            1.0
     VEHICLE_MODEL_DIST   30
     ALIGHTING_TIME 0.00 BOARDING_TIME 0.00 ADDITION YES
     DELAY_TIME 0.00 CAPACITY 999
     COST_COEFFICIENTS 1.000 0.000 1.000
     FEE 0.000 0.000 0.000 0.000
     ATTRACTION 0.000 0.000 0.000 0.000
     DESTINATION 0.000 0.000 0.000 0.000
     POSITION 0.000 0.000 0.000 0.000
     PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE  400
     NAME                  "Motorcycle"
     CATEGORY              BICYCLE
     COLOR_DIST             1
     LENGTH                2.000
     WIDTH                 1.500
     MASS                  1
     POWER                 2
     LAYER                 0
     KATTEMPERATURE        0
     WATERTEMPERATURE      0
     MAX_ACCELERATION      1
     DESIRED_ACCELERATION  7
     MAX_DECELERATION      1
     DESIRED_DECELERATION  1
     EQUIPMENT             NONE
     DRIVER                UNIDENTIFIED
     PASSENGERS            1.0
     VEHICLE_MODEL_DIST   60
     COST_COEFFICIENTS 1.000 0.000 1.000
     FEE 0.000 0.000 0.000 0.000
     ATTRACTION 0.000 0.000 0.000 0.000
     DESTINATION 0.000 0.000 0.000 0.000
     POSITION 0.000 0.000 0.000 0.000
     PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE  500
     NAME                  "LGV"
     CATEGORY              CAR
     COLOR_DIST             1
     LENGTH                10.215
     WIDTH                 0.500
     MASS                  5
     POWER                 5
     LAYER                 0
     KATTEMPERATURE        0
     WATERTEMPERATURE      0
     MAX_ACCELERATION      6
     DESIRED_ACCELERATION  5
```

```
        MAX_DECELERATION      5
      DESIRED_DECELERATION  5
      EQUIPMENT             NONE
      DRIVER                UNIDENTIFIED
      PASSENGERS            1.0
      VEHICLE_MODEL_DIST   20
      COST_COEFFICIENTS 1.000 0.000 1.000
      FEE 0.000 0.000 0.000 0.000
      ATTRACTION 0.000 0.000 0.000 0.000
      DESTINATION 0.000 0.000 0.000 0.000
      POSITION 0.000 0.000 0.000 0.000
      PARKING_AVAILABILITY 0.000 0.000 0.000 0.000
VEHICLE_TYPE  600
      NAME                  "Bike"
      CATEGORY              BICYCLE
      COLOR_DIST             1
      LENGTH                2.000
      WIDTH                 0.500
      MASS                  6
      POWER                 6
      LAYER                 0
      KATTEMPERATURE        0
      WATERTEMPERATURE      0
      MAX_ACCELERATION      6
      DESIRED_ACCELERATION  6
      MAX_DECELERATION      6
      DESIRED_DECELERATION  6
      EQUIPMENT             NONE
      DRIVER                UNIDENTIFIED
      PASSENGERS            1.0
      VEHICLE_MODEL_DIST   60
      COST_COEFFICIENTS 1.000 0.000 1.000
      FEE 0.000 0.000 0.000 0.000
      ATTRACTION 0.000 0.000 0.000 0.000
      DESTINATION 0.000 0.000 0.000 0.000
      POSITION 0.000 0.000 0.000 0.000
      PARKING_AVAILABILITY 0.000 0.000 0.000 0.000


-- Vehicle Classes: --
----------------------

 VEHICLE_CLASS  2
      NAME          "ID C"
      COLOR         NONE
      ANM_ID        "C"
      VEHICLE_TYPES 100
 VEHICLE_CLASS  10
      NAME          "Car"
      COLOR         255 128 64
      ANM_ID        ""
      VEHICLE_TYPES 100
 VEHICLE_CLASS  20
      NAME          "HGV"
      COLOR         BLACK
      ANM_ID        ""
      VEHICLE_TYPES 200 300 500
 VEHICLE_CLASS  30
```

```
       NAME          "Bus"
     COLOR         NONE
     ANM_ID        ""
     VEHICLE_TYPES 300
 VEHICLE_CLASS  50
     NAME          "Pedestrian"
     COLOR         NONE
     ANM_ID        ""
     VEHICLE_TYPES 400 600
 VEHICLE_CLASS  60
     NAME          "Bike"
     COLOR         NONE
     ANM_ID        ""
     VEHICLE_TYPES 600
 VEHICLE_CLASS  70
     NAME          "Motorcycle"
     COLOR         NONE
     ANM_ID        ""
     VEHICLE_TYPES 400

-- Driving Behaviour: --
-----------------------

DRIVING_BEHAVIOR 1 NAME "Urban (motorized)"
   LANE_CHANGE_BEHAVIOR FREE_LANESEL
      T_DISAPPEAR 120.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 0.00
      MIN_ACCELERATION OWN MIN -3.00 DISTANCE 10.00 MAX -1.00
          TRAILING_VEHICLE MIN -2.00 DISTANCE 10.00 MAX -1.00
               COOPERATIVE -2.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL WIEDEMANN74
      NUMB_PRECED 4 OBS_DISTANCE MIN 0.00 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 1.50  CC1 0.90  CC2 4.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR MIDDLE
      OVERTAKE RIGHT  VEHICLE_CLASSES
      OVERTAKE LEFT  VEHICLE_CLASSES
      LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
   AMBER_BEHAVIOR CONT_CHECK
      AMBER_ALPHA 1.59000000 AMBER_BETA1 -0.26000000 AMBER_BETA2 0.27000000
DRIVING_BEHAVIOR 2 NAME "Right-side rule (motorized)"
   LANE_CHANGE_BEHAVIOR RIGHT_HAND_RULE
      T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
      MIN_ACCELERATION OWN MIN -4.00 DISTANCE 200.00 MAX -1.00
          TRAILING_VEHICLE MIN -3.00 DISTANCE 200.00 MAX -0.50
               COOPERATIVE -3.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL WIEDEMANN99
      NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 1.50  CC1 0.90  CC2 4.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR MIDDLE
      OVERTAKE RIGHT  VEHICLE_CLASSES
      OVERTAKE LEFT  VEHICLE_CLASSES
      LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
   AMBER_BEHAVIOR CONT_CHECK
```

```
     AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295
DRIVING_BEHAVIOR 3 NAME "Freeway (free lane selection)"
   LANE_CHANGE_BEHAVIOR FREE_LANESEL
      T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
      MIN_ACCELERATION OWN MIN -4.00 DISTANCE 200.00 MAX -1.00
          TRAILING_VEHICLE MIN -3.00 DISTANCE 200.00 MAX -0.50
               COOPERATIVE -3.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL WIEDEMANN99
      NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 1.50  CC1 0.90  CC2 4.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR MIDDLE
      OVERTAKE RIGHT  VEHICLE_CLASSES
      OVERTAKE LEFT  VEHICLE_CLASSES
      LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
   AMBER_BEHAVIOR CONT_CHECK
      AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295
DRIVING_BEHAVIOR 4 NAME "Footpath (no interaction)"
   LANE_CHANGE_BEHAVIOR FREE_LANESEL
      T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 11.00
      MIN_ACCELERATION OWN MIN -4.00 DISTANCE 100.00 MAX -1.00
          TRAILING_VEHICLE MIN -3.00 DISTANCE 100.00 MAX -1.00
               COOPERATIVE -3.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL NO_INTERACTION
      NUMB_PRECED 2 OBS_DISTANCE MIN 0.00 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 1.50  CC1 0.90  CC2 4.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR ANY
      OVERTAKE RIGHT  VEHICLE_CLASSES
      OVERTAKE LEFT  VEHICLE_CLASSES
      LAT_DISTANCE DEFAULT DY_STAND 1.00 DY_50KMH 1.00
   AMBER_BEHAVIOR CONT_CHECK
      AMBER_ALPHA 1.58858105 AMBER_BETA1 -0.26198070 AMBER_BETA2 0.26945295
DRIVING_BEHAVIOR 5 NAME "Cycle-Track (free overtaking)"
   LANE_CHANGE_BEHAVIOR FREE_LANESEL
      T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 0.00
      MIN_ACCELERATION OWN MIN -4.00 DISTANCE 100.00 MAX -1.00
          TRAILING_VEHICLE MIN -3.00 DISTANCE 100.00 MAX -1.00
               COOPERATIVE -3.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL WIEDEMANN99
      NUMB_PRECED 2 OBS_DISTANCE MIN 10.00 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00  DIAMOND_SHAPE
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 0.50  CC1 0.50  CC2 0.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR RIGHT
      OVERTAKE RIGHT  VEHICLE_CLASSES ALL
      OVERTAKE LEFT  VEHICLE_CLASSES ALL
      LAT_DISTANCE DEFAULT DY_STAND 0.10 DY_50KMH 0.30
   AMBER_BEHAVIOR CONT_CHECK
      AMBER_ALPHA 1.59000000 AMBER_BETA1 -0.26000000 AMBER_BETA2 0.27000000
DRIVING_BEHAVIOR 6 NAME "Motor-Cycle-Track (free overtaking)"
   LANE_CHANGE_BEHAVIOR FREE_LANESEL
      T_DISAPPEAR 60.00 MIN_LC_GAP 0.50 MIN_FREEFLOW 0.00
```

```
MIN_ACCELERATION OWN MIN -3.00 DISTANCE 25.00 MAX -1.00
          TRAILING_VEHICLE MIN -3.00 DISTANCE 25.00 MAX -1.00
               COOPERATIVE -3.00   ABXFACTOR 0.60
   CAR_FOLLOW_MODEL WIEDEMANN74
      NUMB_PRECED 2 OBS_DISTANCE MIN 5.19 MAX 250.00 REAR_OBS_DISTANCE MIN
0.00 MAX 150.00  DIAMOND_SHAPE
      AX_AVERAGE 2.00 BX_ADD 2.00 BX_MULT 3.00
      CC0 1.50  CC1 0.90  CC2 4.00  CC3 -8.00  CC4 -0.35
      CC5 0.35  CC6 11.44  CC7 0.25  CC8 3.50  CC9 1.50
   LATERAL_BEHAVIOR ANY
      OVERTAKE RIGHT  VEHICLE_CLASSES ALL
      OVERTAKE LEFT  VEHICLE_CLASSES ALL
      LAT_DISTANCE DEFAULT DY_STAND 0.50 DY_50KMH 1.00
   AMBER_BEHAVIOR CONT_CHECK
      AMBER_ALPHA 1.59000000 AMBER_BETA1 -0.26000000 AMBER_BETA2 0.27000000

-- Behavior Types: --
---------------------

BEHAVIORTYPE 1 NAME "1 Urban (motorized)"
   DEFAULT DRIVING_BEHAVIOR 1
BEHAVIORTYPE 5 NAME "5 Cycle-Track (free "
   DEFAULT DRIVING_BEHAVIOR 1
BEHAVIORTYPE 1001 NAME "Urban (motorized)"
   DEFAULT DRIVING_BEHAVIOR 1
BEHAVIORTYPE 1002 NAME "Right-side rule (motorized)"
   DEFAULT DRIVING_BEHAVIOR 2
BEHAVIORTYPE 1003 NAME "Freeway (free lane selection)"
   DEFAULT DRIVING_BEHAVIOR 3
BEHAVIORTYPE 1004 NAME "Footpath (no interaction)"
   DEFAULT DRIVING_BEHAVIOR 4
BEHAVIORTYPE 1005 NAME "Cycle-Track (free overtaking)"
   DEFAULT DRIVING_BEHAVIOR 5
BEHAVIORTYPE 1006 NAME "Zone Connector"
   DEFAULT DRIVING_BEHAVIOR 1
BEHAVIORTYPE 1007 NAME "Mottorcyclemix"
   DEFAULT DRIVING_BEHAVIOR 6


-- Display Types: --
--------------------

DISPLAYTYPE  1  NAME  "Road surface gray" COLOR  GRAY
   TEXTURE  -1  0.500000
   MIPMAPPING
DISPLAYTYPE  2  NAME  "ANM Default" COLOR  GRAY
   TEXTURE  -1  0.500000
   MIPMAPPING
DISPLAYTYPE  3  NAME  "Crosswalk" COLOR  WHITE
   TEXTURE  -1  0.500000
   MIPMAPPING
DISPLAYTYPE  4  NAME  "Zone Connector" COLOR  PURPLE
   TEXTURE  -1  0.500000
   MIPMAPPING

-- Links: --
------------
```

```
LINK      1 NAME "" LABEL  0.00 0.00
  BEHAVIORTYPE     1   DISPLAYTYPE     2
  LENGTH  260.604 LANES  1 LANE_WIDTH  3.50 GRADIENT 0.00000   COST 0.00000
SURCHARGE 0.00000 SURCHARGE 0.00000 SEGMENT LENGTH   10.000
  FROM  2707.379 2444.191
  TO    2923.494 2589.823


-- Connectors: --
-----------------

CONNECTOR 10000 NAME "" LABEL  0.00 0.00
  FROM LINK 517 LANES 1 AT 74.396
  OVER 3313.03740 1783.35960 0.00000  OVER 3313.049 1783.408 0.000  OVER
3313.291 1784.404 0.000  OVER 3314.377 1788.870 0.000  OVER 3314.620
1789.865 0.000
  OVER 3314.632 1789.914 0.000
  TO LINK 529 LANES 1 AT 0.075  BEHAVIORTYPE 1  DISPLAYTYPE 2  ALL
  DX_EMERG_STOP 5.000 DX_LANE_CHANGE 200.000
  GRADIENT 0.00000  COST 0.00000  SURCHARGE 0.00000  SURCHARGE 0.00000
  SEGMENT LENGTH 10.000 ANIMATION


-- Toll Pricing Calculation Models: --
--------------------------------------


-- Managed Lanes Facilities: --
-------------------------------


-- Direction Decisions: --
--------------------------


-- Routing Decisions: --
------------------------

ROUTING_DECISION 1 NAME "" LABEL  0.00 0.00
     LINK 212  AT 146.471
     TIME  FROM 0.0 UNTIL 3600.0
     VEHICLE_CLASSES ALL
     ROUTE     3  DESTINATION LINK   404  AT    7.217
       FRACTION 50.000
       OVER 10116   401 10099
     ROUTE     2  DESTINATION LINK   402  AT    0.000
       FRACTION 50.000
       OVER 10117



-- Desired Speed Decisions: --
------------------------------

DESIRED_SPEED_DECISION 37 NAME "" LABEL  0.00 0.00
     POSITION LINK 609 LANE 2 AT 4.066
     VEHICLE_CLASS  10  DESIRED_SPEED 50
     VEHICLE_CLASS  20  DESIRED_SPEED 50
```

```
  VEHICLE_CLASS  30  DESIRED_SPEED 50
VEHICLE_CLASS  50  DESIRED_SPEED 12
VEHICLE_CLASS  60  DESIRED_SPEED 20
VEHICLE_CLASS  70  DESIRED_SPEED 90
TIME FROM 0.0 UNTIL 999999.0


-- Reduced Speed Areas: --
--------------------------

REDUCED_SPEED_AREA 1
     NAME "" LABEL NONE 0.00 0.00
     POSITION LINK 10001 LANE 1 AT 3.302  LENGTH 2.000
     VEHICLE_CLASS 2  DESIRED_SPEED 9 MAX_DECELERATION 2.000
     VEHICLE_CLASS 10  DESIRED_SPEED 9 MAX_DECELERATION 2.000
     VEHICLE_CLASS 20  DESIRED_SPEED 9 MAX_DECELERATION 1.300
     VEHICLE_CLASS 30  DESIRED_SPEED 9 MAX_DECELERATION 1.300
     VEHICLE_CLASS 50  DESIRED_SPEED 9 MAX_DECELERATION 2.000
     VEHICLE_CLASS 60  DESIRED_SPEED 9 MAX_DECELERATION 2.000
     TIME FROM 0.0 UNTIL 999999.0



-- Inputs: --
-------------

INPUT 1
     NAME "" LABEL  0.00 0.00
     LINK 115 Q 100.000 COMPOSITION 1
     TIME FROM 0.0 UNTIL 3600.0



-- Traffic Compositions: --
---------------------------

COMPOSITION     1 NAME "Default"
     KATTEMPERATURE 1
     WATERTEMPERATURE 2
     VEHICLE_TYPE 100 FRACTION 0.830 DESIRED_SPEED 60
     VEHICLE_TYPE 200 FRACTION 0.000 DESIRED_SPEED 40
     VEHICLE_TYPE 300 FRACTION 0.020 DESIRED_SPEED 50
     VEHICLE_TYPE 400 FRACTION 0.010 DESIRED_SPEED 90
     VEHICLE_TYPE 500 FRACTION 0.100 DESIRED_SPEED 50
     VEHICLE_TYPE 600 FRACTION 0.010 DESIRED_SPEED 15


-- Distributions: --
--------------------

DESIRED_SPEED 15  NAME "15 km/h"   0.00 0.000  15.00 0.000  20.00 1.000
DESIRED_SPEED 60  NAME "60 km/h"   0.00 0.000  58.00 0.000  68.00 1.000
DESIRED_SPEED 50  NAME "50 km/h"   0.00 0.000  24.00 0.000  48.00 0.000
56.00 1.000
DESIRED_SPEED 90  NAME "90 km/h"   0.00 0.000   5.00 0.000  25.00 0.000
85.00 0.000  90.00 0.050  92.39 0.165  95.95 0.336  95.95 0.617  97.40
0.804  110.00 0.950  120.00 1.000
DESIRED_SPEED 11  NAME "Car"   0.00 0.000  40.00 0.000  41.65 0.087  43.46
0.150  45.06 0.186  47.52 0.221  49.47 0.252  52.03 0.352  53.23 0.461
```

```
53.83 0.576  54.09 0.705  54.59 0.822  54.59 0.941  58.40 1.000  60.00
1.000
DESIRED_SPEED 40  NAME "40 km/h"   0.00 0.000  20.00 0.000  22.94 0.090
25.20 0.184  27.02 0.234  28.46 0.277  30.09 0.293  31.90 0.308  33.91
0.309  35.73 0.355  37.11 0.383  38.30 0.452  39.30 0.511  40.11 0.564
40.80 0.614  40.86 0.676  40.86 0.726  40.87 0.813  40.87 0.891  41.68
0.925  42.74 0.963  44.21 0.981  45.00 1.000
DESIRED_SPEED  1  NAME "IMO-M 30-50"   3.50 0.000   5.83 1.000
DESIRED_SPEED  6  NAME "Fruin 2"   2.10 0.000   2.56 0.006   3.01 0.032
3.45 0.119   3.90 0.304   4.35 0.516   4.84 0.744   5.28 0.891   5.73 0.968
6.18 0.987   6.62 1.000
DESIRED_SPEED  5  NAME "5 km/h"   4.00 0.000   6.00 1.000
DESIRED_SPEED  4  NAME "Fruin 1"   2.10 0.000   2.56 0.013   3.01 0.071
3.45 0.175   3.90 0.406   4.35 0.685   4.84 0.880   5.28 0.961   5.73 0.981
6.18 0.994   6.62 1.000
DESIRED_SPEED  3  NAME "Predt-Milinski"   0.00 0.000   0.30 0.011   0.90
0.052   1.50 0.138   2.10 0.320   2.70 0.553   3.30 0.713   3.90 0.790
4.50 0.850   5.10 0.893   5.70 0.927   6.30 0.953   6.90 0.976   7.50 0.993
8.10 1.000
DESIRED_SPEED  2  NAME "IMO-F 30-50"   2.60 0.000   4.28 1.000
DESIRED_SPEED 1001  48.00 0.000  58.00 1.000
DESIRED_SPEED 1000  48.00 0.000  58.00 1.000
DESIRED_SPEED 999  48.00 0.000  58.00 1.000
DESIRED_SPEED 10  NAME "ANM"  13.50 0.000  15.00 0.850  16.50 1.000
DESIRED_SPEED  9  NAME "ANM"  22.50 0.000  25.00 0.850  27.50 1.000
DESIRED_SPEED  8  NAME "Stairs Kretz 2"   0.36 0.000   0.54 0.003   0.72
0.008   1.08 0.069   1.26 0.296   1.44 0.689   1.62 0.887   1.80 0.967
1.98 0.985   2.16 0.987   2.34 0.992   2.52 0.995   2.70 0.997   4.14 1.000
DESIRED_SPEED  7  NAME "Stairs Kretz 1"   0.72 0.000   1.08 0.055   1.44
0.452   1.80 0.877   2.16 0.945   2.52 0.973   2.88 0.986   4.68 1.000
DESIRED_SPEED 140  NAME "140 km/h"  80.00 0.000  99.00 0.030  109.00 0.100
121.00 0.260  131.00 0.470  149.00 0.800  165.00 0.930  185.00 0.990
205.00 1.000
DESIRED_SPEED 130  NAME "130 km/h"  80.00 0.000  98.00 0.030  110.00 0.100
130.00 0.680  135.00 0.720  143.00 0.910  155.00 0.970  170.00 1.000
DESIRED_SPEED 120  NAME "120 km/h"  85.00 0.000  105.00 0.030  110.00 0.100
125.00 0.680  140.00 0.910  155.00 1.000
DESIRED_SPEED 100  NAME "100 km/h"  88.00 0.000  95.00 0.030  100.00 0.100
110.00 0.700  120.00 0.910  130.00 1.000
DESIRED_SPEED 85  NAME "85 km/h"  84.00 0.000  88.00 1.000
DESIRED_SPEED 80  NAME "80 km/h"  75.00 0.000  80.00 0.050  90.00 0.800
100.00 0.950  110.00 1.000
DESIRED_SPEED 70  NAME "70 km/h"  68.00 0.000  78.00 1.000
DESIRED_SPEED 30  NAME "30 km/h"  30.00 0.000  35.00 1.000
DESIRED_SPEED 25  NAME "25 km/h"  25.00 0.000  30.00 1.000
DESIRED_SPEED 20  NAME "20 km/h"  20.00 0.000  25.00 1.000
DESIRED_SPEED 12  NAME "12 km/h"  12.00 0.000  15.00 1.000
MASSES  9  NAME "motorcycle"  200.00 0.000  300.00 1.000
MASSES  6  NAME "Bike"  10.00 0.000  19.32 0.056  20.00 1.000
MASSES  8  NAME "Dreyfuss F"  53.40 0.000  62.50 0.500  78.80 1.000
MASSES  7  NAME "Dreyfuss M"  73.70 0.000  83.10 1.000
MASSES  5  NAME "Ped."  30.00 0.000  120.00 1.000
MASSES  4  NAME "Bahn"  23000.00 0.000  58000.00 1.000
MASSES  3  NAME "Bus"  4000.00 0.000  12000.00 1.000
MASSES  2  NAME "Lkw"  2800.00 0.000  40000.00 1.000
MASSES  1  NAME "Pkw"  800.00 0.000  2000.00 1.000
POWER  7  80.00 0.000  1000.00 1.000
POWER  6   0.50 0.000   0.70 1.000
```

```
POWER  5   0.50 0.000   0.70 1.000
POWER  4  300.00 0.000  600.00 1.000
POWER  3  150.00 0.000  300.00 1.000
POWER  2  150.00 0.000  400.00 1.000
POWER  1  55.00 0.000  160.00 1.000
TEMPERATURE  2   0.00 0.000  100.00 1.000
TEMPERATURE  1   0.00 0.000  400.00 1.000
TIMES  1   MEAN 20.0  STANDARD_DEVIATION  2.0


-- Color Distributions: --
--------------------------

COLOR_DIST  83 NAME "Trousers Woman"
   FRACTION  1.000 COLOR  46  47  82
   FRACTION  1.000 COLOR 255 255 255
   FRACTION  1.000 COLOR  30  35  98



-- Vehicle Model Distributions: --
----------------------------------

VEHICLE_MODEL_DIST  121 NAME "Motorcycle"
   FRACTION  0.100
     FILE "#3dmodels#Vehicles\Motorcycle.v3d"  LENGTH  2.000 AXLE FRONT
0.312  AXLE REAR  1.610  SHAFT  0.000  CLUTCH FRONT  0.000  CLUTCH REAR
1.922


-- Functions: --
----------------

MAX_ACCELERATION  5 NAME "LGV"    0.0 250.0   0.0   5.0
  BASE_POINT  0.000 6.000 5.000 7.000  160.000 0.000 0.000 0.000
MAX_ACCELERATION  6 NAME "Bike"    0.0  28.0   0.0   3.5
  BASE_POINT  0.000 1.540 0.000 1.540  2.985 1.587 0.000 1.672  5.041 1.619
0.000 1.762  7.896 1.683 -0.000 1.940  9.293 1.693 0.000 1.968  11.479
1.831 0.124 2.131  12.937 2.208 0.572 2.642  14.881 2.623 1.044 3.162
16.399 2.731 1.163 3.291  19.193 2.866 1.337 3.500  22.048 2.786 1.300
3.500  23.262 2.722 1.270 3.500  24.538 2.674 1.248 3.500  26.410 2.582
1.205 3.500  26.414 2.557 1.193 3.500  30.000 2.468 1.152 3.500  40.000
2.200 1.027 3.500  50.000 1.964 0.917 3.273  60.000 1.751 0.817 2.918
70.000 1.554 0.725 2.590  80.000 1.372 0.640 2.286  90.000 1.200 0.560
2.000  100.000 1.038 0.484 1.730  110.000 0.969 0.452 1.614  120.000 0.899
0.420 1.499  130.000 0.830 0.387 1.384  140.000 0.761 0.355 1.268  150.000
0.692 0.323 1.153  160.000 0.623 0.291 1.038  170.000 0.553 0.258 0.922
180.000 0.484 0.226 0.807  190.000 0.415 0.194 0.692  200.000 0.346 0.161
0.577  210.000 0.277 0.129 0.461  220.000 0.208 0.097 0.346  230.000 0.138
0.065 0.231  240.000 0.069 0.032 0.115  250.000 0.000 0.000 0.000
MAX_ACCELERATION  4 NAME "Motorcycle"    0.0 250.0   0.0   6.9


-- Priority Rules: --
---------------------

PRIORITY_RULE ONLY_OWN_LINK NO
```

Appendix 10.4

```
-- Stop Signs: --
-----------------

STOP_SIGN 1 NAME "" LABEL  0.00 0.00
     POSITION LINK 467 LANE 2 AT 16.095


-- Conflict Areas: --
---------------------


-- Pedestrian Links: --
-----------------------


-- Pedestrian Areas: --
-----------------------


-- Pedestrian Inputs: --
------------------------


-- Levels: --
-------------

LEVEL  0  NAME  "Base"
  HEIGHT  0.000000  YES  YES


-- Pedestrian Types: --
-----------------------


-- Pedestrian Classes: --
-------------------------


-- Pedestrian Compositions: --
------------------------------


-- Pedestrian Behaviour Parameter Sets: --
-----------------------------------------


-- Area Behaviour Types: --
---------------------------


-- Pedestrian Routing Decisions: --
-----------------------------------


-- Pedestrian Routing: --
-------------------------
```

```
-- Pedestrian Travel Times: --
------------------------------


-- Measurement Areas: --
------------------------


-- Area Evaluations: --
-----------------------


-- Signal Controllers (SC): --
------------------------------

SCJ 14  NAME "BF_LMTER"  TYPE FIXED_TIME  CYCLE_TIME 80.0  OFFSET 0.0

SIGNAL_GROUP 10  NAME "BF_LMTER_EW"  SCJ 14  RED_END 0.1  GREEN_END 23.0
TRED_AMBER 2.0  TAMBER 3.0
  SIGNAL_HEAD 101  NAME ""  LABEL  0.00 0.00  SCJ 14   GROUP 10



-- Detectors: --
----------------



-- Public Transport: --
-----------------------



-- Travel Times: --
-------------------

TRAVEL_TIME   AGGREGATION_INTERVAL 99999 FROM 0 UNTIL 99999 RAW NO
AGGREGATE YES


-- Delays: --
-------------



-- Data Collection: --
----------------------

CROSS_SEC_MEASUREMENT  FROM 0 UNTIL 99999  AGGREGATION_INTERVAL 99999
                     RAW NO  AGGREGATE NO VISUM_ONLINE NO
                     CONFIG_FILE ""



-- Queue Counters: --
---------------------
```

Appendix 10.4

```
-- Data Collection Points: --
-----------------------------



-- Evaluations: --
------------------

EVALUATION  DATABASE "Provider=Microsoft.Jet.OLEDB.4.0" CONFIRM_OVERWRITE
NO

EVALUATION  TYPE  VEHICLE_RECORD  VEH_NUMBERS   CONFIG_FILE "112.1.fzk"
FILTER_FILE "112.fil"
            TIME FROM 0.0 UNTIL 99999.0

EVALUATION  TYPE  PATHEVAL  PARKING_LOTS   CONFIG_FILE "29.wgk"
FILTER_FILE "29.1.wgf"
            TIME FROM 0.0 UNTIL 99999.0

EVALUATION  TYPE  CONVERGENCE  EDGE LENGTH 20.000
            TIME FROM 0.0 UNTIL 999999.0

WINDOW TYPE VEHICLE_INFO CONFIG_FILE "116.fzi"
WINDOW TYPE LDP SIGNAL_GROUP NUMBER DETECTOR NUMBER
                SCJ
WINDOW TYPE SZP SIGNAL_GROUP NUMBER DETECTOR NUMBER
                SCJ

-- Parking Lots: --
-------------------

PARKING_LOT 1 NAME "" LABEL  0.00 0.00
  ZONES      1  FRACTION   1.000
  POSITION LINK 177 AT 111.634
  LENGTH     90.277
  CAPACITY   100
  OCCUPANCY  0
  VEHICLE_CLASS 70  DESIRED_SPEED 60
  DEFAULT DESIRED_SPEED 15
  OPEN_HOURS  FROM 0  UNTIL 99999
  MAX_TIME 99999
  FLAT_FEE 0.0
  FEE_PER_HOUR 0.0
  ATTRACTION 0.0
PARKING_LOT 2 NAME "" LABEL  0.00 0.00
  ZONES      2  FRACTION   0.000
  POSITION LINK 176 AT 34.528
  LENGTH     17.813
  CAPACITY   100
  OCCUPANCY  0
  DEFAULT DESIRED_SPEED 60
  OPEN_HOURS  FROM 0  UNTIL 99999
  MAX_TIME 99999
  FLAT_FEE 0.0
  FEE_PER_HOUR 0.0
  ATTRACTION 0.0
```

Appendix 10.4

```
-- Nodes: --
------------

  NODE 1 NAME "" LABEL  0.00 0.00
  EVALUATION NO
    NETWORK_AREA 4  4457.112 3400.387  4463.408 3314.940  4473.602 3308.943
4490.392 3380.599
  NODE 2 NAME "" LABEL  0.00 0.00
  EVALUATION NO
    NETWORK_AREA 4  4324.372 3404.000  4308.611 3343.084  4433.424 3328.175
4414.255 3383.979
  NODE 3 NAME "" LABEL  0.00 0.00
  EVALUATION NO
    NETWORK_AREA 4  2538.504 687.305  2728.715 509.917  2638.953 383.821
2397.448 574.033


-- Edge Closure: --
-------------------


-- TEAPAC: --
-------------


-- Emissions: --
----------------

EMISSION
        LAYERS ""
     AIR_DENSITY  1.202
     TEMPERATURE 20.000

-- Static 3D Models: --
-----------------------


-- Pavement Markers: --
-----------------------




-- Keyframes: --
----------------

-- 3D Traffic Signal Object Defaults: --
----------------------------------------
 V3D_SIGNAL_ARMS_END

 V3D_SIGNAL_HEADS

        SIG_

V3D_SIGNAL_HEADS_END

V3D_SIG_DEFAULTS_END
```

```
-- 3D Traffic Signal Data: --
-----------------------------


-- Texture Lists: --
--------------------


-- Compass: --
--------------


-- 3D Settings: --
------------------

V3D_LOD  799.990 800.000 800.010

-- ANM Settings: --
-------------------
```

Appendix 11- a to d

Example of emission factor coefficients of CO, HC, NOX and fuel consumption of NAEI database UK

Appendix 11- a

CO Emission Factor - Speed Coefficients

Based on review and assessment of new factors for Euro I and II vehicles given in TRL
Database of Emission Factors, September 2001 (Barlow, Hickman and Boulter)
and reconsideration of scaling factors for Euro III, IV vehicles by NETCEN

EF(g/km) = (a + b.v + c.v^2 + d.v^e + f.ln(v) + g.v^3 + h/v + i/v^2 + j/v^3).x

v is speed in kph

Emission Function
Test Speed/kph

			a	b	c	d	e	f	g	h	i	j	x	40
Petrol car	Pre- ECE	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	2.62	29.795
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	2.62	25.343
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	2.62	23.480
	ECE 15.00	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	1.87	21.249
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	1.87	18.073
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	1.87	16.745
	ECE 15.01	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	1.87	21.249
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	1.87	18.073
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	1.87	16.745
	ECE 15.02	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	1.55	17.613
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	1.55	14.981
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	1.55	13.880
	ECE 15.03	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	1.62	18.487
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	1.62	15.725
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	1.62	14.569
	ECE 15.04	< 1.4 l	14	-0	0	0	0	0	0	158	0	0	1	11.383
		1.4 - 2.0 l	9.5	-0	0	0	0	0	0	179	0	0	1	9.682
		> 2.0 l	9.7	-0	0	0	0	0	0	244	0	0	1	8.970
	Euro I	< 1.4 l	4.2	-0					0		360		1	1.500
		1.4 - 2.0 l	0.6						0		980	-2383	1	1.305
		> 2.0 l	0		0					112			1	3.074
	Euro II	< 1.4 l	0.4	-0						44.2			1	1.461
		1.4 - 2.0 l	0.5							8.01			1	0.710
		> 2.0 l	-0	0						12.8			1	0.145
	Euro III	< 1.4 l	0.4	-0						44.2			0.9	1.315
		1.4 - 2.0 l	0.5							8.01			0.9	0.639
		> 2.0 l	-0	0						12.8			0.9	0.131
	Euro IV	< 1.4 l	0.4	-0						44.2			0.6	0.876
		1.4 - 2.0 l	0.5							8.01			0.6	0.426
		> 2.0 l	-0	0						12.8			0.6	0.087
Motorcycles	Pre-2000	moped (2-s)	6.5	0.4	0				0	0	0	0	1	22.640
		<250cc 2-s	21	0.1	0				0	-17.6	0	0	1	23.136
		<250cc 4-s	2.1	0	0				0	770	-2360	0	1	24.385
		250-750cc 4-s	9.3	0	0				0	490	-1436	0	1	22.451
		>750cc 4-s	5	0	0				0	414	-1196	0	1	16.973
	97/24/EC	moped (2-s)	6.5	0.4	0				0	0	0	0	0.10	2.264
		<250cc 2-s	21	0.1	0				0	-17.6	0	0	0.52	11.920
		<250cc 4-s	2.1	0	0				0	770	-2360	0	0.29	7.014
		250-750cc 4-s	9.3	0	0				0	490	-1436	0	0.31	7.045
		>750cc 4-s	5	0	0				0	414	-1196	0	0.43	7.279

Source: Compiled by NAEI
NETCEN

Factors from petrol car factors CO_HC.xls etc, Mcycle EF-Speed coeffs_2.xls
June 2002

Appendix 11- b

HC Emission Factor - Speed Coefficients

Based on review and assessment of new factors for Euro I and II vehicles given in TRL
Database of Emission Factors, September 2001 (Barlow, Hickman and Boulter)
and reconsideration of scaling factors for Euro III, IV vehicles by NETCEN

EF(g/km) = (a + b.v + c.v^2 + d.v^e + f.ln(v) + g.v^3 + h/v + i/v^2 + j/v^3).x

These are VOCs, including methane v is speed in kph

			a	b	c	d	e	f	g	h	i	j	x	**Emission Function Test Speed/kph** 40
Petrol car	Pre- ECE	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1.58	2.472464237
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1.58	2.444191787
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1.58	2.294357895
	ECE 15.00	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1.23	1.935744144
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1.23	1.913609049
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1.23	1.79630095
	ECE 15.01	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1.23	1.935744144
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1.23	1.913609049
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1.23	1.79630095
	ECE 15.02	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1.25	1.953595752
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1.25	1.931256525
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1.25	1.8128666
	ECE 15.03	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1.25	1.953595752
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1.25	1.931256525
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1.25	1.8128666
	ECE 15.04	< 1.4 l	1.9	-0	0	0	0	0	0	19	0	0	1	1.567828
		1.4 - 2.0 l	2.1	-0	0	0	0	0	0	17	0	0	1	1.5499
		> 2.0 l	1.2	-0	0	0	0	0	0	26	0	0	1	1.454888
	Euro I	< 1.4 l	-1	0						19	-92.3	186	1	0.08951875
		1.4 - 2.0 l	0.1	-0	0					3.5			1	0.08555
		> 2.0 l	-0	0						7.2		-42	1	0.16012375
	Euro II	< 1.4 l	0.2	-0	0								1	0.08284
		1.4 - 2.0 l	0.1								12.1		1	0.0576625
		> 2.0 l	-0	-0						1.2			1	0.027702
	Euro III	< 1.4 l	0.2	-0	0								0.7	0.057988
		1.4 - 2.0 l	0.1								12.1		0.7	0.04036375
		> 2.0 l	-0	-0						1.2			0.7	0.0193914
	Euro IV	< 1.4 l	0.2	-0	0								0.53	0.0439052
		1.4 - 2.0 l	0.1								12.1		0.53	0.030561125
		> 2.0 l	-0	-0						1.2			0.53	0.01468206
Motorcycles	Pre-2000	moped (2-s)	3.8	0.2	0				0	0	0	0	1	11.73
		<250cc 2-s	5.8	0	0				0	168	-436	0	1	9.756716
		<250cc 4-s	0.1	0	0				0	63	0	-657	1	1.699834375
		250-750cc 4-s	0.1	0	0				0	55	0	-517	1	1.519489875
		>750cc 4-s	0.5	0	0					90	0	-1064	1	2.701875
	97/24/EC	moped (2-s)	3.8	0.2	0				0	0	0	0	0.22	2.5806
		<250cc 2-s	5.8	0	0				0	168	-436	0	0.69	6.747437088
		<250cc 4-s	0.1	0	0				0	63	0	-657	0.49	0.827857029
		250-750cc 4-s	0.1	0	0				0	55	0	-517	0.55	0.835816321
		>750cc 4-s	0.5	0	0					90	0	-1064	0.29	0.796788532

Source: Compiled by NAEI
NETCEN

Factors from petrol car factors CO_HC.xls etc, Mcycle EF-Speed coeffs_2.xls
June 2002

Appendix 11- c

Nox Emission Factor - Speed Coefficients

Based on review and assessment of new factors for Euro I and II vehicles given in TRL
Database of Emission Factors, September 2001 (Barlow, Hickman and Boulter)
and reconsideration of scaling factors for Euro III, IV vehicles by NETCEN

EF(g/km) = (a + b.v + c.v^2 + d.v^e + f.ln(v) + g.v^3 + h/v + i/v^2 + j/v^3).x

v is speed in kph

			a	b	c	d	e	f	g	h	i	j	x	**Emission Function Test Speed/kph** 40
Petrol car	Pre- ECE	< 1.4 l	1.17	0	-0	0	0	0	0	0	0	0	1.00	1.849
		1.4 - 2.0 l	1.36	0	-0	0	0	0	0	0	0	0	1.00	2.164
		> 2.0 l	1.5	0	0	0	0	0	0	0	0	0	1.00	2.86
	ECE 15.00	< 1.4 l	1.17	0	-0	0	0	0	0	0	0	0	1.00	1.849
		1.4 - 2.0 l	1.36	0	-0	0	0	0	0	0	0	0	1.00	2.164
		> 2.0 l	1.5	0	0	0	0	0	0	0	0	0	1.00	2.86
	ECE 15.01	< 1.4 l	1.17	0	-0	0	0	0	0	0	0	0	1.00	1.849
		1.4 - 2.0 l	1.36	0	-0	0	0	0	0	0	0	0	1.00	2.164
		> 2.0 l	1.5	0	0	0	0	0	0	0	0	0	1.00	2.86
	ECE 15.02	< 1.4 l	1.48	-0	0	0	0	0	0	0	0	0	1.00	1.619
		1.4 - 2.0 l	1.66	-0	0	0	0	0	0	0	0	0	1.00	1.831
		> 2.0 l	1.87	-0	0	0	0	0	0	0	0	0	1.00	2.066
	ECE 15.03	< 1.4 l	1.62	-0	0	0	0	0	0	0	0	0	1.00	1.68
		1.4 - 2.0 l	*************** E.F. = 1.29.exp(.0099*v) ********										1.00	1.91677142
		> 2.0 l	2.78	-0	0	0	0	0	0	0	0	0	1.00	2.8064
	ECE 15.04	< 1.4 l	1.12	0	0	0	0	0	-0	0	0	0	1	1.381952
		1.4 - 2.0 l	1.35	0	0	0	0	0	0	0	0	0	1	1.7424
		> 2.0 l	1.91	0	0	0	0	0	0	0	0	0	1	2.09048
	Euro I	< 1.4 l	0.16						0	2.8			1	0.257804
		1.4 - 2.0 l	-0.4	0						13	-51.5	81.1	1	0.226579688
		> 2.0 l	0.39		-0				0			70	1	0.30177375
	Euro II	< 1.4 l	0.25	-0					0	0.2			1	0.152358
		1.4 - 2.0 l	0.3						0				1	0.314736
		> 2.0 l	0.27	-0					0				1	0.175592
	Euro III	< 1.4 l	0.25	-0					0	0.2			0.6	0.0914148
		1.4 - 2.0 l	0.3						0				0.6	0.1888416
		> 2.0 l	0.27	-0					0				0.6	0.1053552
	Euro IV	< 1.4 l	0.25	-0					0	0.2			0.32	0.04875456
		1.4 - 2.0 l	0.3						0				0.32	0.10071552
		> 2.0 l	0.27	-0					0				0.32	0.05618944
Motorcycles	Pre-2000	moped (2-s)	0.03	0	0				0	0	0	0	1	0.03
		<250cc 2-s	0.02	0	0				0	0	0	0	1	0.029884
		<250cc 4-s	0.06	0	0				-0	0	0	0	1	0.1416304
		250-750cc 4-s	0.1	0	0				0	0	0	0	1	0.112512
		>750cc 4-s	0.16	0	0				0	0.7	0	0	1	0.21365
	97/24/EC	moped (2-s)	0.03	0	0				0	0	0	0	0.33	0.0099
		<250cc 2-s	0.02	0	0				0	0	0	0	0.78	0.023172324
		<250cc 4-s	0.06	0	0				-0	0	0	0	1.43	0.202580526
		250-750cc 4-s	0.1	0	0				0	0	0	0	1.37	0.153969756
		>750cc 4-s	0.16	0	0				0	0.7	0	0	1.26	0.269589001

Source: Compiled by NAEI
NETCEN

Factors from petrol car factors CO_HC.xls etc, Mcycle EF-Speed coeffs_2.xls
June 2002

<u>Appendix 11- d</u>

Fuel Consumption Emission Factor - Speed Coefficients

Based on review and assessment of new factors for Euro I and II vehicles given in TRL Database of Emission Factors, September 2001 (Barlow, Hickman and Boulter)

EF(g/km) = (a + b.v + c.v^2 + d.v^e + f.ln(v) + g.v^3 + h/v + i/v^2 + j/v^3).x

v is speed in kph

														Emission Function Test Speed/kph
			a	b	c	d	e	f	g	h	i	j	x	40
Petrol car	Pre- ECE	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1.35	70.72525118
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1.33	80.61572985
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1.35	103.9330065
	ECE 15.00	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1.19	62.47584248
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1.16	70.6252327
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1.07	82.13337188
	ECE 15.01	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1.19	62.47584248
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1.16	70.6252327
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1.07	82.13337188
	ECE 15.02	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1.11	58.16866508
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1.08	65.44404383
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1.12	85.79761139
	ECE 15.03	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1.11	58.16866508
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1.08	65.44404383
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1.12	85.79761139
	ECE 15.04	< 1.4 l	68.2	-1	0	0	0	0	0	98.1	6282	-19055	1	52.42868353
		1.4 - 2.0 l	53.7	-1	0	0	0	0	0	901	0	0	1	60.64340937
		> 2.0 l	75.5	-1	0	0	0	0	0	1215	0	0	1	76.76471301
	Euro I	< 1.4 l	54.4	-1	0	0	0	0	0	400	86.64	7005	1	49.71805877
		1.4 - 2.0 l	34.8	-0	0	0	0	0	0	979	489.8	-1191	1	60.24757061
		> 2.0 l	38.5	0	0	0	0	0	0	1468	0	-42.45	1	76.17017579
	Euro II	< 1.4 l	29.3	-0	0	0	0	0	0	542	0	0	1	43.63087119
		1.4 - 2.0 l	36.3	-0	0	0	0	0	0	655	12.23	0	1	53.47693173
		> 2.0 l	80.4	-1	0	0	0	0	0	612	0	0	1	66.38459586
	Euro III	< 1.4 l	0.25	-0					0	0.18			0.6	0.0914148
		1.4 - 2.0 l	0.3						0				0.6	0.1888416
		> 2.0 l	0.27	-0					0				0.6	0.1053552
	Euro IV	< 1.4 l	0.25	-0					0	0.18			0.32	0.04875456
		1.4 - 2.0 l	0.3						0				0.32	0.10071552
		> 2.0 l	0.27	-0					0				0.32	0.05618944
Motorcycles	Pre-2000	moped (2-s)	25										1	25
		<250cc 2-s	45.8	-1	0	0	0	0	-0	0	0	0	1	30.44083048
		<250cc 4-s	70.8	-2	0	0	0	0	-0	0	0	0	1	23.7677924
		250-750cc 4-s	102	-3	0	0	0	0	-0	0	0	0	1	29.6833312
		>750cc 4-s	120	-4	0	0	0	0	-0	0	0	0	1	38.503544
	97/24/EC	moped (2-s)	25	0	0	0	0	0	0	0	0	0	0.44	11
		<250cc 2-s	18	0.2	-0	0	0	0	0	0	0	0	1.00	23.96492974
		<250cc 4-s	79.9	-2	0	0	0	0	-0	0	0	0	1	26.8534328
		250-750cc 4-s	79.9	-2	0	0	0	0	-0	0	0	0	1	26.8534328
		>750cc 4-s	79.9	-2	0	0	0	0	-0	0	0	0	1	26.8534328

Source: Compiled by NAEI
NETCEN

Factors from petrol car factors CO_HC.xls etc, Mcycle EF-Speed coeffs_2.xls
June 2002