ESTIMATION OF MOTOR VEHICLE EMISSIONS WITH RESPECT TO CONTROLLING AIR POLLUTION

Hussam Achour, B.Eng.

PhD **2012**

ESTIMATION OF MOTOR VEHICLE EMISSIONS WITH RESPECT TO CONTROLLING AIR POLLUTION

by

Hussam Achour

(B.Eng.)

Thesis presented to Dublin City University in fulfilment of the requirement for the degree of Doctor of Philosophy

School of Mechanical and Manufacturing Engineering

Dublin City University

Ireland

September 2012

Supervisor: Dr. Abdul Ghani Olabi

Declaration

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Doctor of Philosophy is entirely my own work, that I have exercised reasonable care to ensure that the work is original, and does not to be the best of my knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledge within the text of my work.

Signed: ___________________   ID No: 55158447   Date____________________

Acknowledgements

Firstly, all praise is to Allah for giving me the strength to carry out this challenging task. This thesis could not have been done without other contributions that have to be acknowledged. Firstly, I would like to thank my supervisor Dr Abdul Ghani Olabi for his guidance, support and help over the past few years. This work could not have been done without his encouragement and direction.

I also would like to thank those who offered their cars to do the tests on, Mr Cien Merne, Dr Ahmad Issa, Dr Osama Basmaji, Dr Abdullah Marashly.

Thanks to Darren Hugges and Luke Galvin who helped me in my research as part of their Master degree research and final year project work respectively.

I would also like to extend my sincere gratitude to the research staff in Trinity College Dublin, Dr. Tony Robinson, and Mr. Gerry Byrne for their time and efforts to start this research using their equipment firstly.

I also would like to thank those in UCD, Dr David Timoney, Dr Edward Casey, and Dr Will Smith for their help and advice.

Secondly, I would also like to acknowledge the generous funding for my work by Aleppo University and thanks to Mr. Andrew Clarke and Miss Evelyn Campbell for English proof.

Last but not least I would like to thank my father Safwan for his continuous encouragement, my mother Amal Shrayyef for her prayer for me, my brothers Kinan, Muhammad and Rama. Big thanks to my lovely wife Rima Kotiny for her enormous help and patience which made my job easier, thanks to my lovely daughters Raghad and Hala who made my life happier. Thanks to my mother-in-law (my aunt) for her continuous prayer for me. Thanks to my friends Abed, Ahmad, Mustafa, Shadi, and Evelyn in DCU. Thanks to Dr Khaled Binyounis for his help and support.

Dedication

This thesis is dedicated to those who have sacrificed their lives to free Syria.

H.A

Publications

This work has been disseminated through the following publications:

Peer Reviewed Journals:

[1] **Hussam Achour,** James Carton and Abdul Ghani Olabi, Estimating Vehicle Emission from Road Transport, case study: Dublin City. Applied Energy, Volume 88, Issue 5, May 2011, Pages 1957-1964

[2] **Hussam Achour,** A. Marashly, A. G. Olabi, (2012), "Assessing Energy Consumption of the Transport Sector in Aleppo, SYRIA", Journal of Sustainable Manufacturing and Renewable Energy. Vol. 1 Issue 3-4, pages 1-15.

Conference Proceedings

[1] **Hussam Achour** and Abdul Ghani Olabi, Driving Cycle Developments And Their Impacts On Energy Consumption Of Transportation. Proceeding of the 5th International Conference on Sustainable Energy & Environmental Protection Part 1, p20-25, 05th -08th June 2012, Dublin, Ireland.

[2] **Hussam Achour** and Abdul Ghani Olabi and Abdullah Marashly, Development of a practical driving cycle for simulation of car emissions: a case study in Aleppo city, Syria, 5th Dubrovnik Conference on Sustainable Development of Energy Water and Environment Systems (SDEWES2009), September 29 - October 3 2009, Dubrovnik, Croatia.

[3] **Hussam Achour** and Abdul Ghani Olabi, Comparison between measured and estimated vehicle emissions from road transport. Proceeding of the 3rd International Conference on Sustainable Energy & Environmental Protection Part 1, p24-29, 12th -15th August 2009, Dublin, Ireland.

[4] **Hussam Achour** and Abdul Ghani Olabi, Estimating on-road emissions using a special driving cycle for Dublin, International Conference on Simulation Based Engineering and Sciences (TCN CAE 2008), 16th - 17th October 2008, Venice, Italy.

Symposiums

[1] **Hussam Achour** and Abdul Ghani Olabi, Estimating Vehicle Emission from Road Transport, Faculty Research Day, Faculty of Engineering and Computing, (FRD2010), 12th May 10, Dublin City University, Ireland.

[2] **Hussam Achour** and Abdul Ghani Olabi, Estimating Vehicle Emission by Using COPERT-4 Software for a Specific Driving Cycle in Dublin, Symposium for Mechanical Engineering Research and Practice (SMERP2008),29th August 2008, Dublin City University, Ireland.

List of content

List of Figures

List of Tables

List of Abbreviations

2 D	Two dimentions
ARTEMIS	Assessment and Reliability of Transport Emission Models and Inventory Systems
BDC	Bottom dead centre
CI	Compression ignition
CO	Carbon Oxides
COPERT	COmputer Programme to estimate Emissions from Road Transport
DDC	Dublin Driving Cycle
EDC	European driving cycle
EEA	European Environment Agency
EF	Emission Factor
EGR	Exhaust Gas Recalculations
EU	European Union
FC	Fuel Consumption
Fe	Vehicle Motion
H2O	Water
HC	Hydrocarbon
IMEP	Inlet mean effective pressure
Mv	Vehicle Mass
N2	Nitrogen Dioxide
NEDC	New European Driving Cycle
Nm	Torque unit
NMHC	Non-Methane hidrocarbon
NO2	Nitrogen Dioxide
O2	Oxygen
OBD	On-board Diagnostic
OSPM	Operational Street Pollution Model
PM	Particulate Matter
Ps	Specific Power

RPM	Engine speed
SI	Spark Ignition
TDC	Top dead centre
TRL	Transport Research Laboratory
v	Vehicle Speed

Abstract

ESTIMATION OF MOTOR VEHICLE EMISSIONS WITH RESPECT TO CONTROLLING AIR POLLUTION

Hussam Achour

Air pollution is becoming a very important issue for the transportation sector, particularly car emissions in urban areas, and there is much interest in evaluating the actual level of emissions across Europe and around the World. The effects of vehicle emissions can be seen from both a human perspective and an environmental perspective. The emissions from cars can have a deadly consequence on human life, as seen with the CO emission, which has been proven to be fatal to human life in a confined space. In addition, research has shown that the exposure to fuel emissions can have a carcinogenic effect on humans. This is a huge concern for people as the amount of traffic increases globally. On the other hand, energy consumption from the transport sector in many developing countries has not been dealt with the same intensity as that of developed countries. Due to the rapidly expanding mobile populations in the developing world, the issue of low carbon development and transport needs to be urgently addressed. For these reasons, Aleppo city in the developing country of Syria was under investigation through this research in order to evaluate the traffic emissions in such a busy city and provide local government access to reliable tools that can accurately estimate the contribution of traffic related pollutant levels to local emissions inventories.

In this research, COPERT, one of most commonly deployed tools has been used which makes use of bulk traffic movements and average vehicle speeds in order to estimate emissions. The combination of On-board diagnostic data extraction incorporated in all modern passenger cars and COPERT emission factors have been employed to allow for the real world vehicular activity in order to better estimate the contribution of private cars to local emissions inventories. A built-in data acquisition package has been developed in LabVIEW in order to log and save the data extracted from OBD system. This data is then analyzed to obtain driving cycles of specified routes which have been plotted so that emission factors could be obtained. Advantages of this method are that it is easy to follow, inexpensive and the results are in a good fit to the estimated values. A common method involves the use of gas analyzers which measure resultant emissions directly from the exhaust manifold. Such equipment is generally expensive, difficult to calibrate and rather bulky. However it has been used at the early stage of this research for evaluating the results obtained by the estimation method where different routes of Dublin city, time and cars have been used in order to give a preliminary case study of a standard driving cycle in the urban area of Dublin city. Good correlations between the predicted results of the modeling packages and the actual data obtained by direct measurement are still maintained. After this stage, the same method has been employed in Aleppo city in order to establish a representative tool for the local authority in identifying the air quality caused by traffic emissions. As each

country has a unique driving cycle which represents the characteristics of the driving and the real amount of emissions from vehicles, individual testing is necessary for each region. Comprehensive study of the two cities with all data obtained has been done and recommendations for future work have been included.

Chapter 1 Introduction

1.1 Motivation of the study

Urban air pollution is one of the major problems confronting the world population [1]. Due to the introduction of recent legislative laws, there has been an urgent need to find appropriate methods of vehicle emission measurement. These means of emission measurement are to ensure the control of the amount of toxic gases these vehicles produce and release into the atmosphere. The harmful emissions that are produced from the exhaust pipes of these vehicles are Hydrocarbons (HC), Nitrogen Oxides (NOx), Carbon monoxide (CO), Carbon dioxide (CO2), Particulate Matter (PM) and Sulphur Oxide (SOx). The consequences of these emissions entail air pollution, smog, acid rain, liver damage, cancer, heart disease and acceleration in global warming.

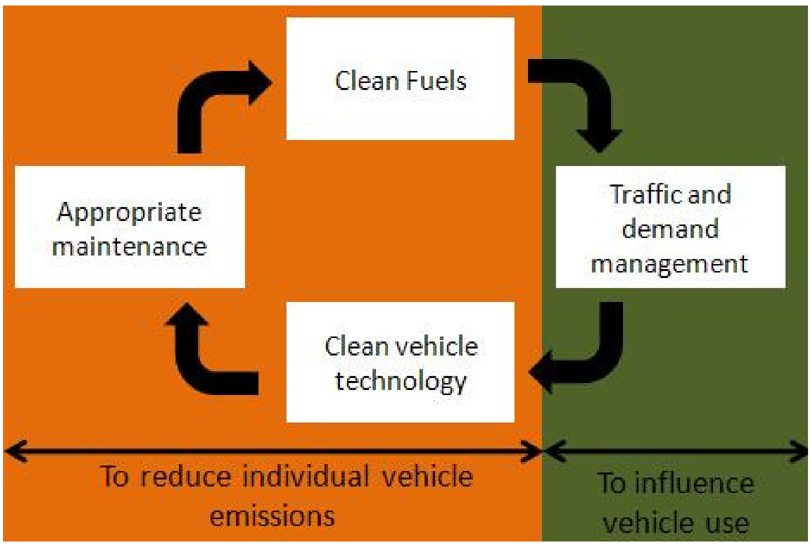


Figure 1.1: Emission reduction approaches.

Car manufacturers and drivers can help reduce these harmful emissions in three separate ways: Figure 1.1.

1. Increasing engine efficiency i.e. electronic ignition, fuel injection systems and electronic control units which control the amount of fuel wasted in the engines fuel system.

2. Increasing vehicle efficiency i.e. lightweight vehicle design, reduced air resistance, improved powertrain efficiency and regenerative braking.

3. Standardized driving technique, unobstructed traffic conditions, cruising at an optimum speed for the vehicle and the reduction of cold starts.

As an example of decreasing emission through engine technology, Three-way catalytic converter, Figure1.2, is used nowadays and this has three simultaneous tasks:

- Reduction of nitrogen oxides through conversion to nitrogen and oxygen:

$$2NOx \rightarrow xO2 + N2$$

- Oxidation of carbon monoxide to carbon dioxide:

$$2CO + O2 \rightarrow 2CO2$$

- Oxidation of un-burnt hydrocarbons (HC) to carbon dioxide and water:

$$2CxHy + (x+y)\ O2 \rightarrow 2xCO2 + yH2O$$

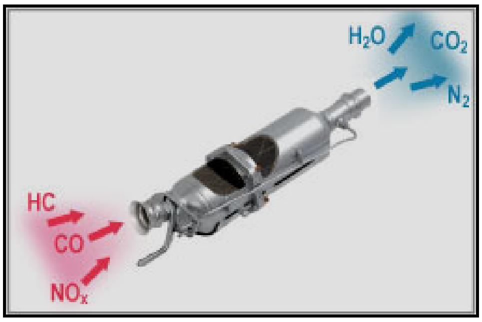


Figure 1.2: Three-way catalytic converters.

These converters help in limiting pollution emitted from vehicles and a new standard emission limitation comes every few years to control pollutant in new vehicles. In the table 1.1, European emission standards for passenger cars showed a decrease in emission limits for newer cars.

Table 1.1: European emission standards for passenger cars (Category M*), g/km [2]

Tier	Date	CO	THC	NMHC	NOx	HC+NOx	PM	P***
Diesel								
Euro 1 +	July 1992	2.72 (3.16)	-	-	-	0.97 (1.13)	0.14 (0.18)	-
Euro 2	January 1996	1.0	-	-	-	0.7	0.08	-
Euro 3	January 2000	0.64	-	-	0.50	0.56	0.05	-
Euro 4	January 2005	0.50	-	-	0.25	0.30	0.025	-
Euro 5	September 2009	0.500	-	-	0.180	0.230	0.005	-
Euro 6 (future)	September 2014	0.500	-	-	0.080	0.170	0.005	-
Petrol (Gasoline)								
Euro 1	July 1992	2.72(3.16)	-	-		0.97 (1.13)	-	-
Euro 2	January 1996	2.2	-	-		0.5	-	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-	-
Euro 5	September 2009	1.000	0.100	0.068	0.060	-	0.005**	-
Euro 6 (future)	September 2014	1.000	0.100	0.068	0.060	-	0.005**	-
*Before Euro 5, passenger vehicles >2500 kg were type approved as light commercial vehicles N_1– I **Applies only to vehicles with direct injection engines *** A number standard is to be defined as soon as possible and at the latest upon entry into force of Euro 6 + Values in brackets are conformity of production (COP) limits								

There are numerous ways of measuring emissions such as theoretical, experimental and real life measurements. Some of these methods will be described in the following sections:

1- MOBILE6 Vehicle Emission Modeling Software

MOBILE6 is an emission factor model for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions.

2- Operational Street Pollution Model (OSPM)

OSPM is a street canyon model as seen in Figure 1.3; it can be used to assess pollution resulting from traffic in streets. Concentrations of exhaust gases are calculated using a combination of a plume model for the direct Contribution and a box model for the recirculation part of the pollutants in the street.

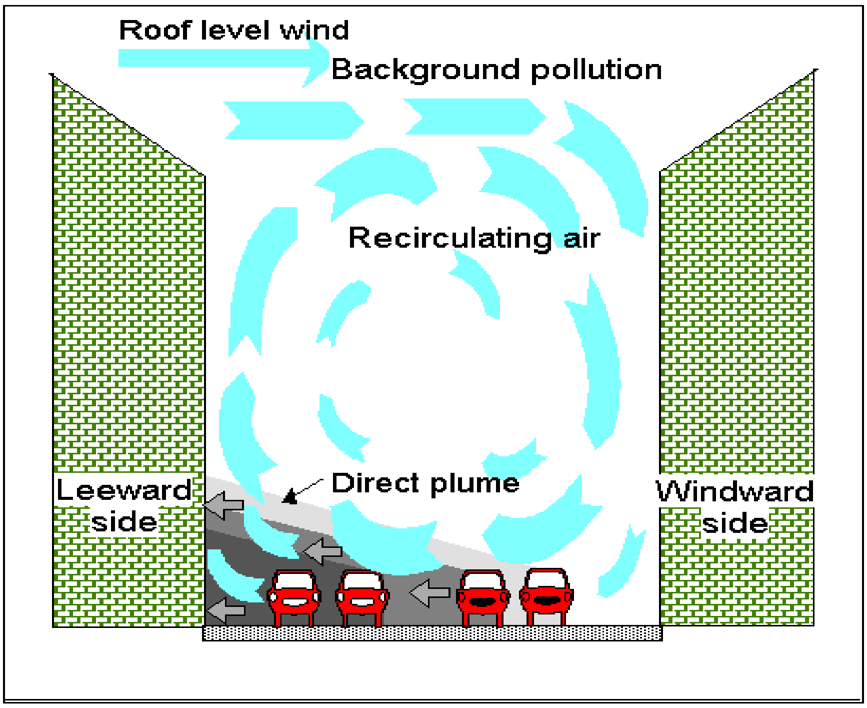


Figure 1.3: Operational Street Pollution methodology.

3- COPERT 4 (COmputer Programme to estimate Emissions from Road Transport).

COPERT 4 is a Microsoft Windows software program which is developed as a European tool for the calculations of emissions from the road transport sector. The emissions calculated include regulated (CO, NOx, VOC, PM) and unregulated pollutants (N2O, NH3, SO2, NMVOC speciation). Figure 1.4 shows the model and version of the software used in this research.

Figure 1.4: The software model and version used in this research.

The use of software such as COPERT 4 has been in effect for numerous years. It uses equations to interpret the expulsion of emissions from combustion engines. It takes parameters from certain vehicles such as engine size, the technology level and the average speed in kilometres per hour and gives the resultant in (g/km). From calculation of these equations, theoretical values for each particular emission can be obtained. These values can be very accurate but are still only theoretical and do not take into account the drivers influence on the car, more details will come in the literature review.

The use of On Board Diagnostics (OBD) signal interpreter known as the Elm scan 5 Figure 1.5, can return values for emissions. OBD can also determine the driving cycle. The driving cycle gives the general traffic conditions that the car is being driven in, and also how the car is being driven by the driver. The aim of this project is to estimate vehicle emissions by defining this driving cycle. The use of the OBD and configured LabVIEW software helps display numerous helpful characteristics for this report such as Acceleration (m/s^2), Deceleration (m/s^2), Engine speed (RPM), Vehicle speed (Km/h) and time parameters (which in turn can be used to define the drive cycle), and even the engine coolant temperature (C°).

Figure 1.5: Elm Scan 5 communicator [3].

Both of these previous methods for emission analysis give theoretical and experimental values for emission measurement. However, these methods can't give real world results taking into account weather effects on emission measurement as a principle example. Humidity, air temperature, altitude, rain, snow and other seasonal effects have a large influence on the emissions measured. For validation purposes, a gas analyzer has been used in parallel with the other equipment in order to validate the results.

The Autologic gas analyzer is a portable gas analyzer which runs on a Pocket PC, (also can run on a windows PC or laptop), Figure 1.6. The analyzer is designed to be used in a real life environment where both high durability and excellent accuracy are critical to diagnose vehicle emissions. An emission sample probe hooks up to the exhaust, where emissions pass into the gas analyzer. The gas analyzer sends data via Bluetooth to the Pocket PC. Autologic software interprets the data and displays the emission information on screen. The gas analyzer measures 5 types of gas HC, CO, CO_2, NOx and O_2.

Figure 1.6: Autologic gas analyzer. [5]

1.2 Objective of the study

The motivation for this work can be concluded in the following sectors:

- Develop portable reliable equipment at low cost so as to be able to monitor local emissions of the transport sector.

- Develop a preliminary Drive Cycle for two cites.

- Provide local government access to reliable tools that can accurately estimate the contribution of traffic related pollutant levels to local emissions Inventories.

Figure 1.7 shows the Schematic of hypothesis being targeted in order to implement the objective of this study.

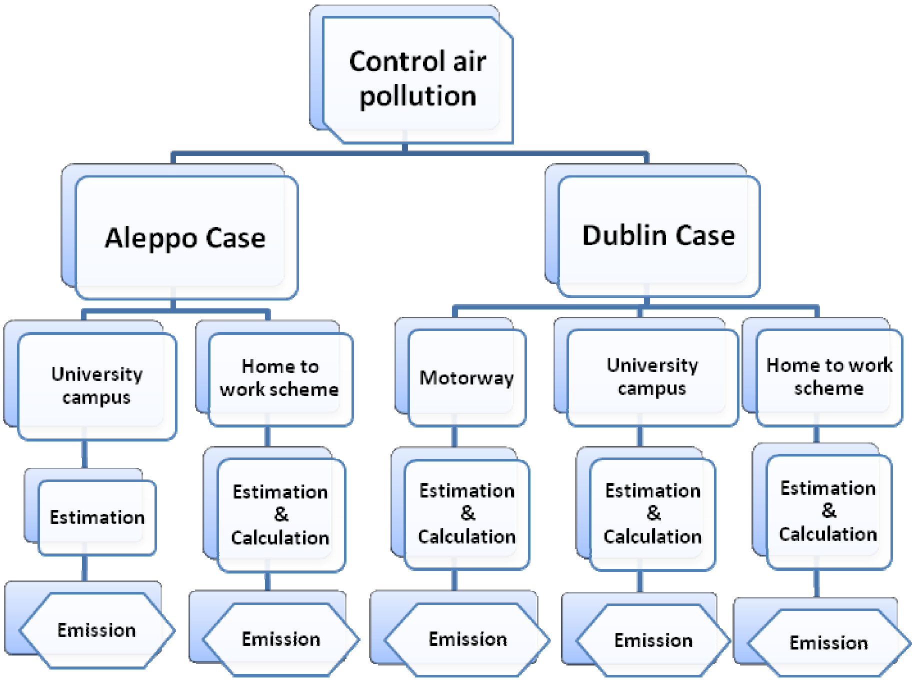


Figure 1.7: Schematic of hypothesis being targeted

1.3 Structure of the thesis

The thesis is arranged as follows:

Chapter 2 (Literature review):

- Information and theory relating to the fundamentals of combustion and engine technology
- Review of emission legislation and testing through EU emission standards and drive cycles.
- Review of calculation methods of emission inventories addressed, two types of models are explained in detail
- Short review of the comparison of vehicle emissions measurement techniques.
- Comparison of vehicle emissions modelling techniques developed. The flow chart of chapter 2 is shown in Figure 1.8

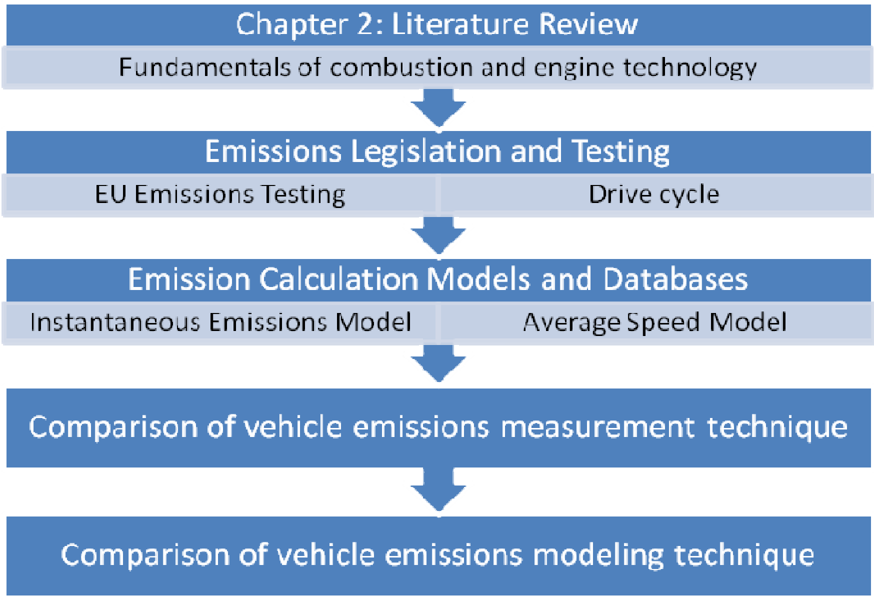


Figure 1.8: Flow chart of chapter 2

Chapter 3 (Experimental Work):

- Information on experimental work, testing steps, equipment used and the characterisation of the trips chosen
- Testing preparation
- Information on data obtained.

Chapter 4 (Results and Discussion):

- Presents the results for each technique used
- Explains and discusses the results observed for each analysis in detail

Chapter 5 (Conclusion and Future work):

- Presents conclusions, contributions and some recommendations for future work.

The list of references and appendices are presented at the end of this thesis. Figure 1.9 shows the flow chart of the overall structure of the thesis.

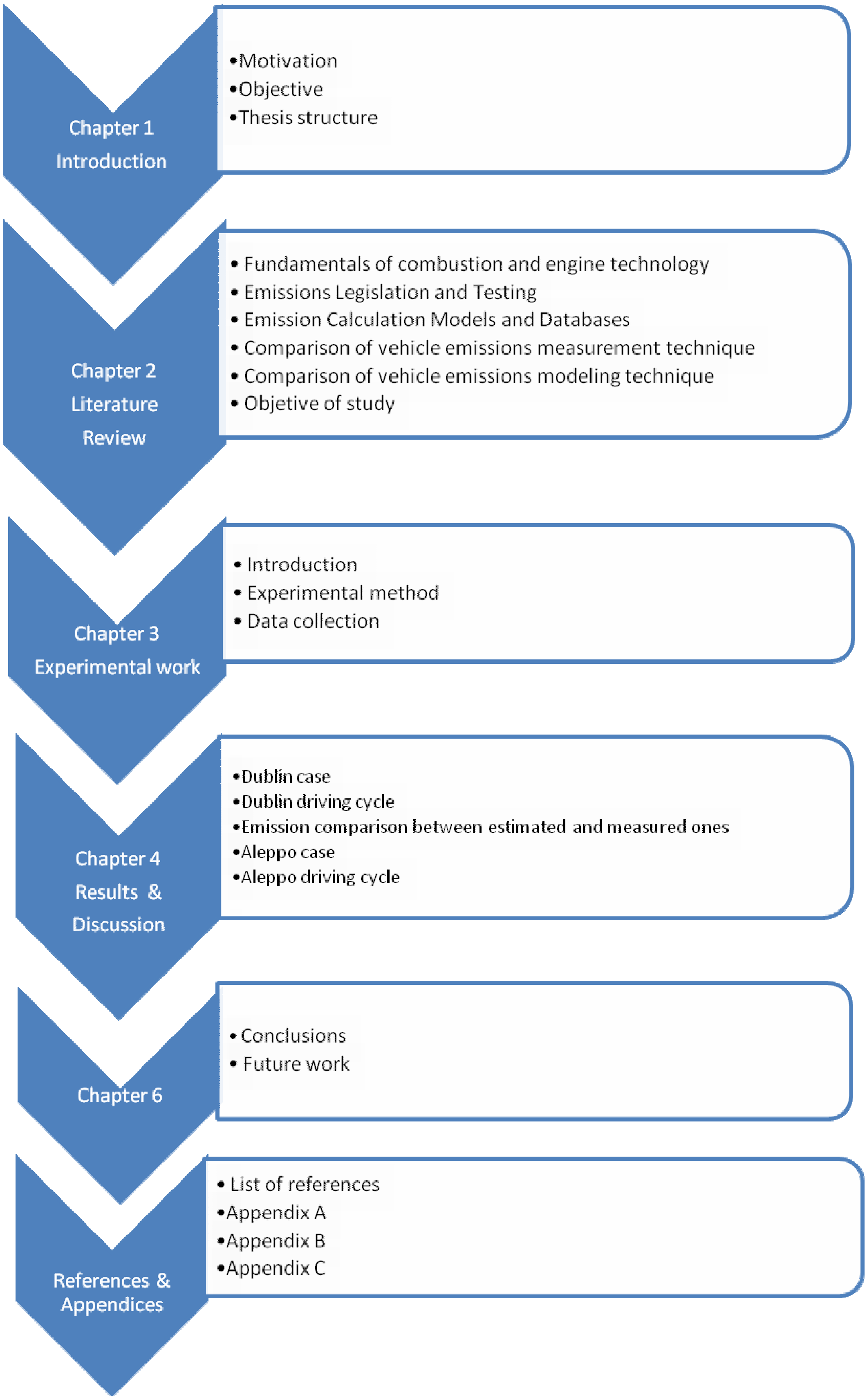


Figure 1.9: Flow chart of the structure of thesis

Chapter2 Literature Review

The fundamentals of combustion and engine technology have been addressed in this dissertation as an introduction of this study. This includes a brief review of emission inventories and methods of quantifying and how to reduce them.

2.1 Design and Operation of Spark Ignition and Compression Ignition Engines

Internal combustion engines work by converting the chemical energy found in fuel into mechanical power. This energy is released by oxidizing (burning) the fuel in the combustion chamber inside the engine. The internal combustion engines studied for this project is the spark ignition. The components used in both engines differ somewhat. The spark ignition (SI) engine injects the air/fuel mix into the combustion chamber which is then ignited using the spark plug. The compression ignition (CI) engine compresses the air in the combustion chamber and then the fuel is injected into the cylinder alone which is then compressed to a point where the mix spontaneously combusts causing the crank to rotate [5]. Therefore the combustion process in the compression ignition occurs at constant pressure, whereas the combustion process in the spark ignition occurs at constant volume.

The SI and CI engines are known as reciprocating engines. With a reciprocating engine, the piston moves up and down in the cylinder and transmits power through a connecting rod and crank mechanism connected to the drive shaft. The steady rotation of the crank produces a cyclical motion. There are two types of cycles used for reciprocating engine known as the two-stroke and the four-stroke. The two-stroke uses only one rotation of the crank to complete combustion of the air/fuel mix. The four-stroke, Figure 2.1, uses two rotations to achieve the same effect, [5]. The four stroke engine is the mainly used with passenger vehicles and was used for this study.

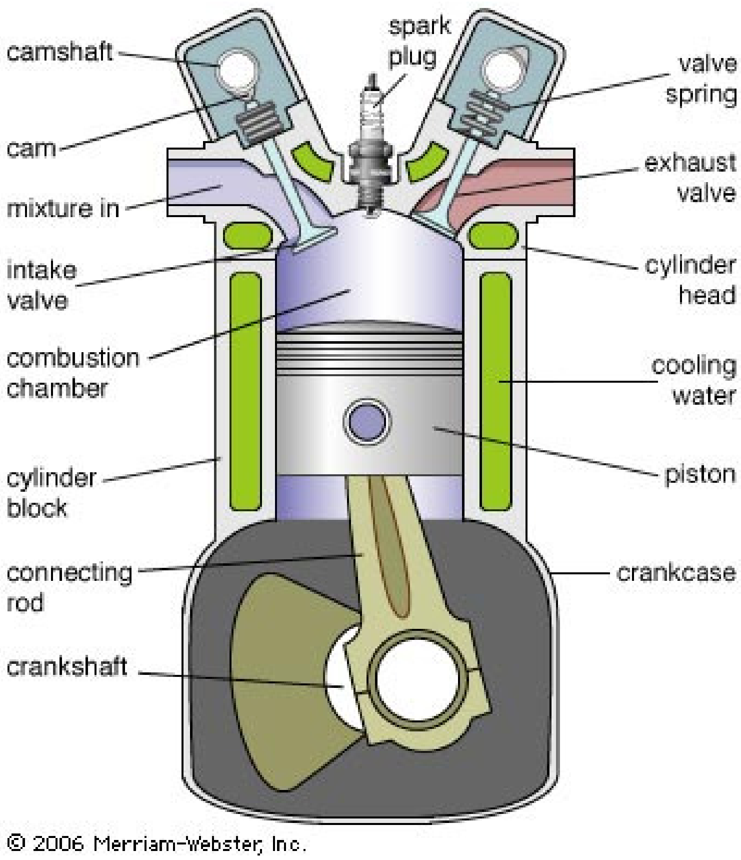


Figure 2.1: Design of an internal combustion Engine Cylinder [6]

1. *An intake stroke*, Figure 2.2, which starts at top dead centre (TDC) and ends with the piston at bottom dead centre (BDC), which draws fresh mixture into the cylinder. To increase the mass inducted, the inlet valve opens shortly before the stroke starts and closes shortly before it ends.

2. *A compression stroke*, when both valves are closed and the mixture inside the cylinder is compressed to a small fraction of its initial volume. Toward the end of the compression stroke, combustion is initiated and pressure rises more rapidly.

3. *A power stroke,* or expansion stroke, which starts with the piston at TDC and ends at BDC as the high-temperature, high-pressure, gases push the piston down and force the crank to rotate. About five times as much work is done on the piston during the power stroke as the piston had to do during compression.

As the piston approaches BDC the exhaust valve opens to initiate the exhaust process and drop the cylinder pressure close to the exhaust pressure.

4. *An exhaust stroke,* where the remaining burned gases exit the cylinder. These burned gases exit as the pressure may be substantially higher than the exhaust pressure. The exhaust gases are swept out by the piston moving towards TDC. As the piston approaches TDC the inlet valve opens. Just after TDC the exhaust valve closes and the cycle starts again.

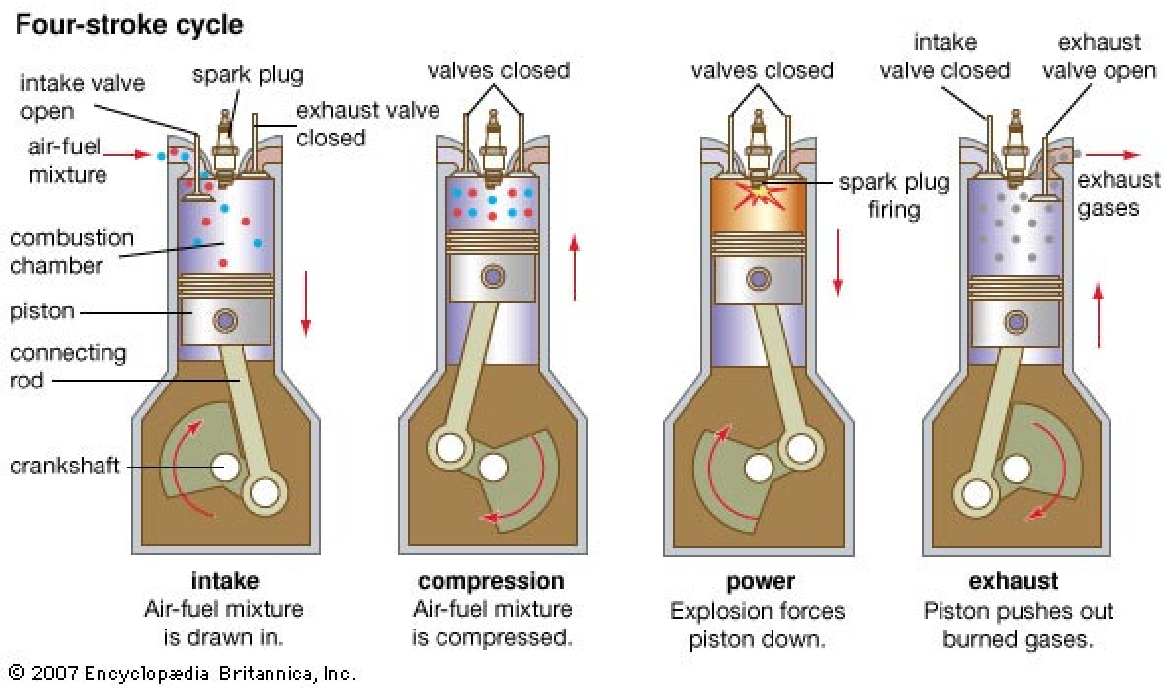


Figure 2.2: Four Stroke Spark Ignition Combustion Process [6]

2.2 Combustion of Hydrocarbon fuels

A fuel can be defined as any material that can be burned to release chemical energy [5]. The reaction that occurs when a fuel is burned is known as combustion. There is a certain amount of air that is needed to complete the combustion process. This air is known as stoichiometric or theoretical air. During combustion, all the fuel is burned with the air theoretically available. The burning of air available is known as stoichiometric combustion of that fuel, Figure 2.3.

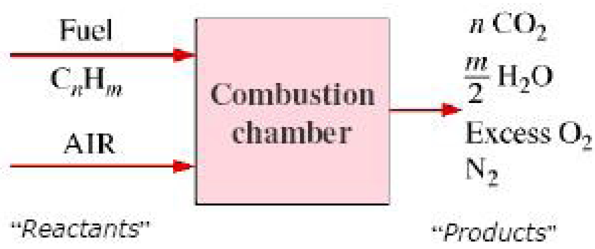


Figure 2.3: Ideal Combustion of a Hydrocarbon Fuel in a Combustion Chamber [7]

During the combustion process, the components that exist before the reaction are known as the reactants and the components which exist after the reaction are known as the products [7]. Chemical equations are balanced on the basis of the conservation of mass principle. Chemical equations are balanced on the basis of the conservation of mass principle, which states that the total mass of each element is conserved during the chemical reaction. The equation below describes the ideal combustion of octane (C_8H_{18}), a commonly used hydrocarbon fuel, in air.

$$C_8H_{18}+12.5O_2+(12.5)(3.76)N2 \rightarrow 8CO_2+9H_2O+47N_2 \qquad (2.1)$$

This equation can be extended to give the general case as shown below

$$C_aH_b+(a+\frac{b}{4})O_2+3.76N_2 \rightarrow aCO_2+\frac{b}{2}H_2O+3.76(a+\frac{b}{4})N_2 \qquad (2.2)$$

As can be seen from the above equations, CO_2, H_2O and N_2 are the only products in idealised stoichiometric combustion process of a hydrocarbon fuel in air. In reality however, many other intermediate products are also formed. These products are formed for reasons such as dissociation, additives present in the fuel and the alteration of the air/fuel ratio to optimise the operation of the engine. In the case of octane, the air/fuel ratio on a mass basis is given by

$$\frac{A}{F} = \frac{(59.5)(28.96)}{(1)(114)} = 15.1 \qquad (2.3)$$

2.3 Pollutant formation

Air pollution in urban areas is a very relevant and topical problem. Over the past fifty years, the emissions produced from internal combustion engines have come under increased scrutiny due to their negative contribution to urban air pollution. Emissions can be categorized into three groups.

Evaporative Emissions

Evaporative emissions occur through the vehicle fuel system (carburettor, storage tank, flow pipes). They occur due to fuel volatility and daily variation in temperature [8].

Engine-Out Emissions

Engine out emissions refer to emissions prior to any chemical change that happens in the exhaust chamber.

Tail Pipe Emissions

Tail pipe emissions refer to emissions values after the catalytic reactions have taken place. These values are generally referred as emission limit figures. CO production is strongly related to the air/fuel ratio compared to other negligible factors [7]. CO emissions occur due to the quenching of the reaction in equation 2.4 at about 1700K [9].

$$C02 + H2O \leftrightarrow CO + H2O \quad (2.4)$$

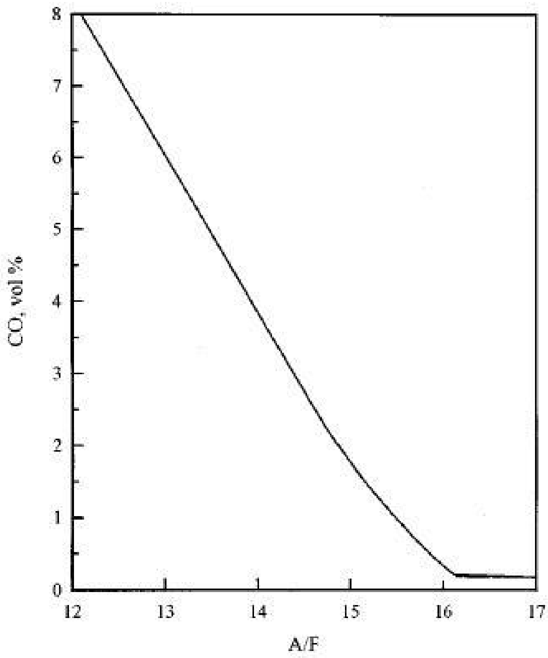


Figure 2.4: CO Emissions of SI engine vs Air/Fuel ratio [7]

The Figure 2.4 above shows the affect of air/fuel ratio on CO emissions. It is shown that at rich conditions, the CO content is significantly higher (factor of 10) than at stoichiometric.

With lean mixtures, CO can be generated due to a poor mixture, some local rich regions, incomplete combustion, and a lack of time for the oxidation of CO to CO2 to reach equilibrium [8].

2.3.1 NOx Emissions

NOx is the term that relates to all oxides of nitrogen emissions from engines [5]. NOx emissions consist almost entirely of NO (90-98%) [7]. the catalyst for NO to be formed from oxygen is given by the Zeldovitch mechanism.

$$O + N_2 \leftrightarrow NO + N \qquad (2.5)$$

$$N + O_2 \leftrightarrow NO + O \qquad (2.6)$$

$$N + OH \leftrightarrow NO + H \qquad (2.7)$$

It has been seen that the temperature of the burned gases and the level of NO formed indicates that thermodynamic equilibrium is not obtained in the timescale of engine combustion [9]. The production of NOx heavily depends on the combustion temperature and available oxygen [7]. NO formation increases exponentially with temperature. This shows that the peak NO emissions occur at slightly lean mixtures (Ø=0.9) [9]. It can be seen from the Arrhenius Equation how the rate of NO formation varies with both temperature and oxygen concentration.

$$\frac{d[NO]}{dt} = \frac{Const}{T^{1/2}}.\exp\left(\frac{-Ea}{T}\right).[N_2]_e.[O_2]^{0.5}{}_e \qquad (2.8)$$

Where

- d[NO]/dt is the rate of formation
- **T** is the temperature at which NOx formation occurs
- Ea is the activation energy
- $[N2]_e$ and $[O2]^{0.5}{}_e$ are the equilibrium concentrations of nitrogen and oxygen in a mixture dissociated at high temperatures

Equation 2.8 explains why the majority of engine related parameters (load, air/fuel ratio, spark timing, ignition angle, and compression ratio) have a major influence on NOx formation. It is noted that NOx emissions vary considerably with parameters affecting local temperatures [8]. NOx formation is generally formed in the post flame region where temperatures are high enough (reached 2000°C) [8].

2.3.2 HC Emissions

Hydrocarbons refer to the unburned hydrocarbons in the fuel that have not changed during the combustion process and products resulting from various hydrocarbon reactions [9]. Four major mechanisms for HC emission formation have been clearly identified [5]. A stroke by stroke diagram of HC formation can be seen in Figure 2.5.

Flame Quenching

Flame quenching has been considered for a long time to be the primary source of HC emissions [9]. This process occurs on the walls of the combustion chamber. The cool walls act as a heat sink thus reducing the cylinder temperature and affecting the fuel combustion.

Filling of crevice volumes during compression and combustion strokes

Unburned HC will remain in areas where the flame does not propagate [8]. Crevice volumes can be defined as narrow regions in the combustion chamber into which the flame cannot enter due to heat transfer to the walls [5]. The largest crevice volumes are spaces between piston, piston rings and cylinder walls. Crevice volumes are highly dependent on crevice entry geometry and crevice surface area.

Incomplete Combustion

Incomplete combustion refers to the bulk quenching of the flame in the fraction of the cycle where combustion is particularly slow [5]. Such conditions are likely to occur during transient engine operation. During this period, the air-fuel ratio, spark timing, and fraction of gas recycled for emission control may not be properly matched.

Absorption of fuel vapour into oil layers on cylinder during compression and intake

Studies have shown that the addition of engine oil to fuel can result in two or three times the HC emissions from a clean engine [5]. It has been speculated that this increase is due to the absorption of fuel vapour into the lubricating oil layers.

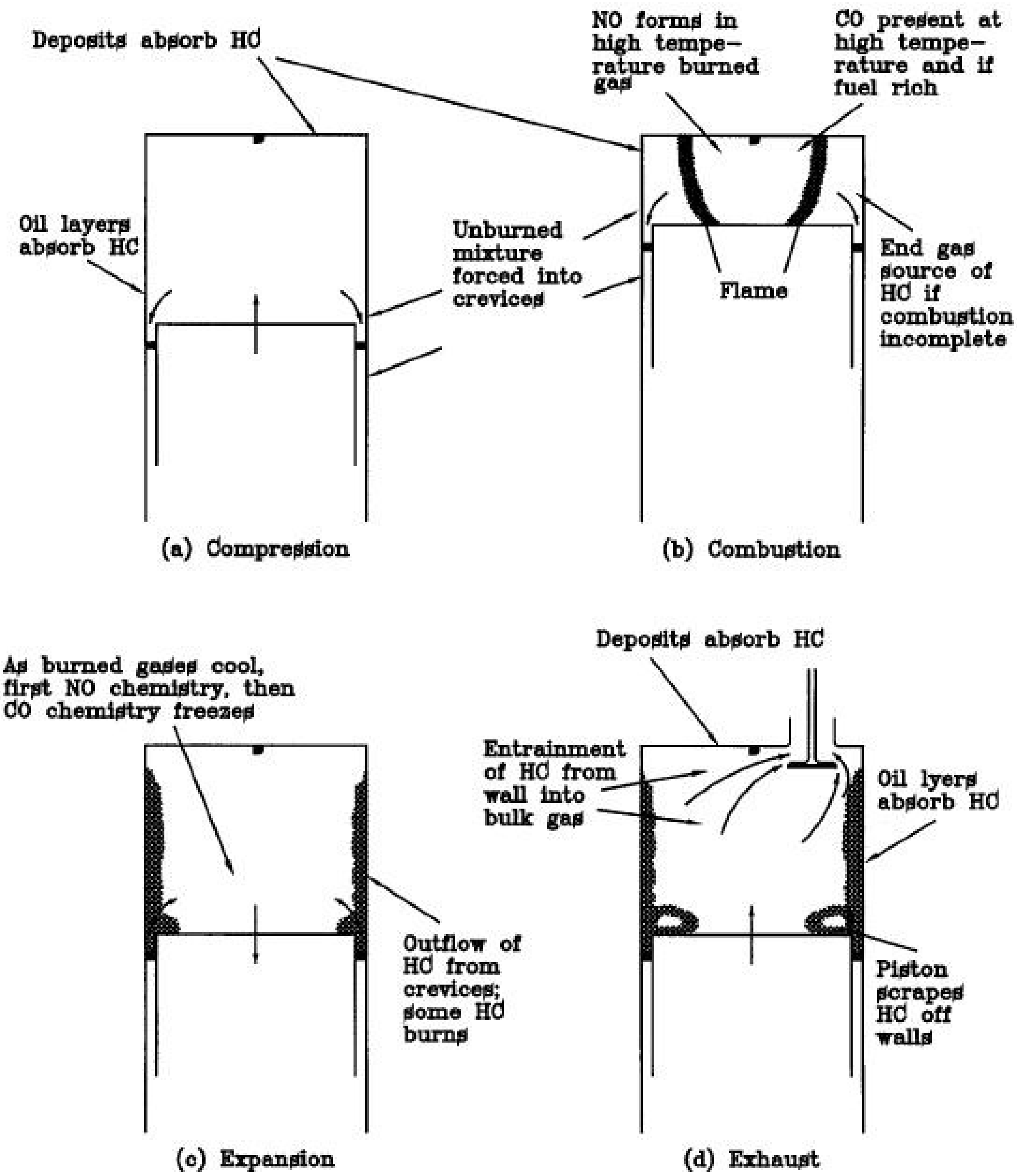


Figure 2.5: Formation of Hydrocarbon mechanisms in a Spark ignited internal combustion engine [8].

2.3.3 Particulates

Particulate Emissions are mainly related to diesel engines. This is due to soot forming from the carbon in the diesel fuel. Particulate formation takes place in a combustion environment of 1000K to 2800K and at pressures of 50 to 100atm. The formation occurs due to a deficiency of air in the combustion chamber. The carcinogenic and mutagenic soot particles are formed by oxygen-deficient thermal cracking of long chained molecules. Particulate emissions consist of a solid and a liquid state. Figure 2.6 shows the overall composition of diesel exhaust gas.

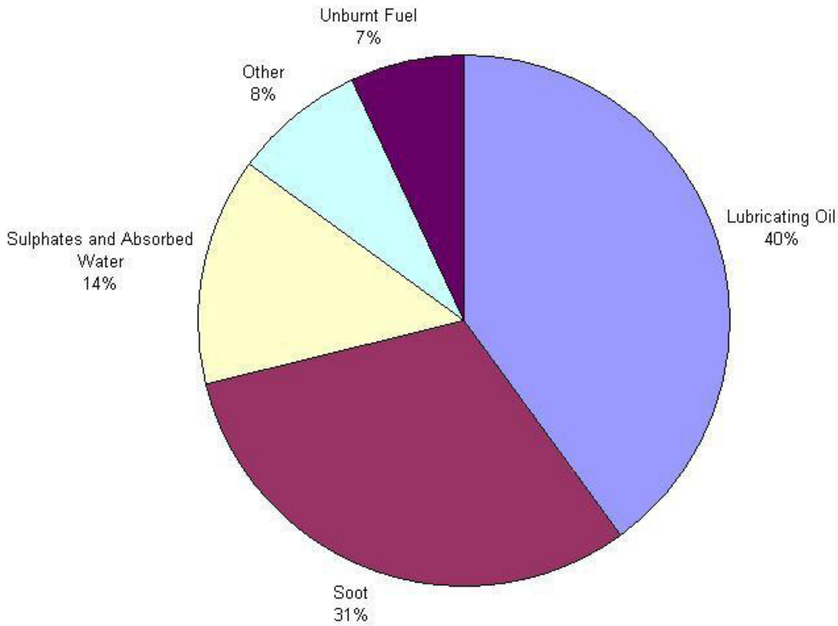


Figure 2.6: Particulate Matter Composition of a Diesel Engine.

2.3.4 Engine Performance Maps

Engine maps are graphical methods used by Engineers to show the fuel consumption and emissions of engines. Fuel consumption and emissions depend on the operating state of the engine. Fuel consumption and emissions are assessed on the basis of the vehicle parameters [10] such as engine speed [RPM] and torque [Nm] [5]. ISO curves of the fuel consumption or emissions [g/h] can be plotted on a two dimensional map of speed and torque. The figure 2.7 shows a typical NOx map. Note that the units of NOx in this case are kg/h. From these maps, it is possible to analyze fuel consumption/emissions under different operating conditions.

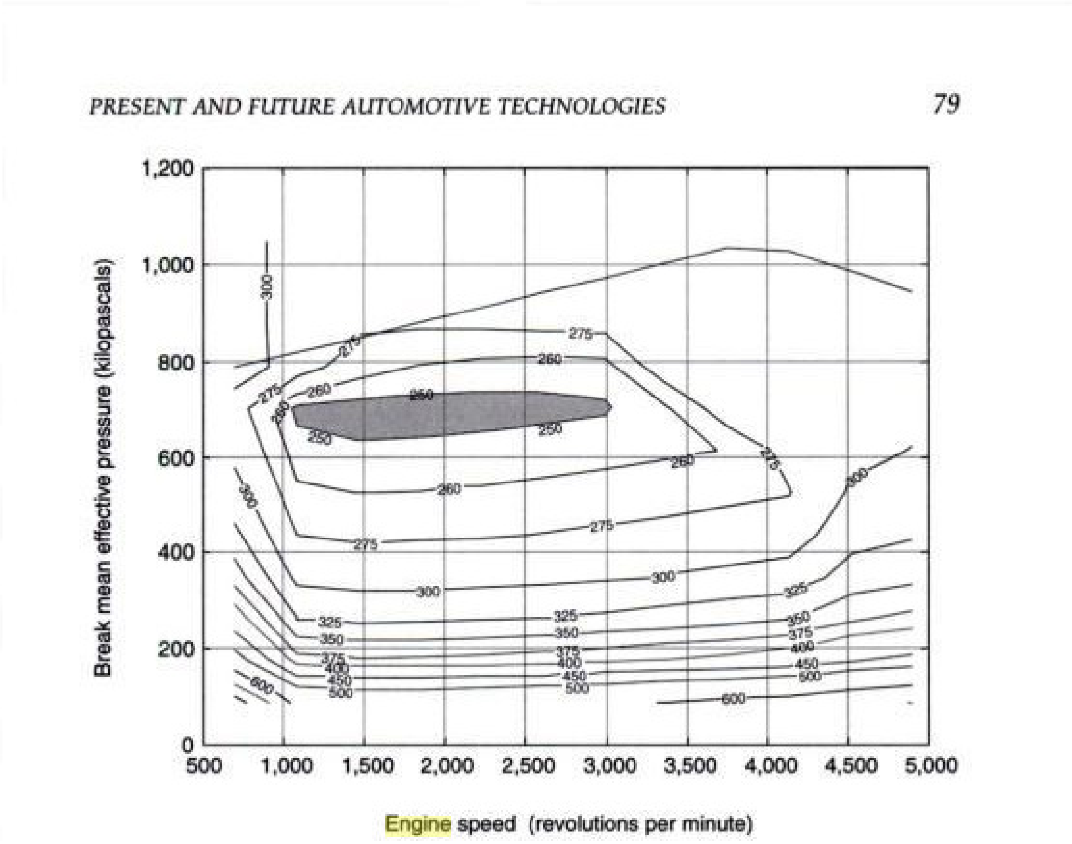


Figure 2.7: Typical Engine performance map for a spark ignition engine [11]

It can be very expensive and time consuming to fully map an engine. This requires the use of a bench test. A typical method for an engine is to hold one engine parameter constant and steadily increase the other [5]. Generally, torque is held constant and speed is steadily increased from idle to maximum. For each discrete torque value, only one data set is obtained. A significant number of test runs do need to be carried out in order to completely define an engine.

It is possible to reduce the workload associated with engine mapping by using a chassis dynamometer [9] although this can lead to significant drive train losses during testing.

2.3.5 Design and Operational Factors Affecting Emissions

The maximum efficiency of the spark ignition and compression engine is limited by a number of factors. These factors can range from friction induced losses to losses from cooling. Efficiency is calculated by the extent by which the charge in the cylinder is compressed before combustion. This calculation of efficiency is known as the geometric compression ratio [12]. Two areas of interest arise when comparing the relative efficiency of a petrol engine and a diesel engine. Firstly, power is controlled by throttling the air/fuel charge at part load conditions. This throttling process has an inherent inefficiency. Secondly, the limiting factor of the geometric compression ratio of a petrol engine is a function of the tendency of the fuel used to resist knock (Premature combustion). For reasons of pollutant control, A/F ratio is maintained as close to stoichiometric as possible. An improvement in efficiency may be achieved using a higher A/F ratio.

2.3.6 Spark Ignition Engines

After an in-depth review of spark ignition engines the following list has been compiled detailing the most important emission related factors.

- Spark and timing
- Engine speed and load
- Air/Fuel ratio
- Valve timing
- Exhaust gas recirculation (EGR)
- Coolant Temperature

2.3.7 Spark Timing

The timing of the spark within the combustion chamber controls the time in which the combustion begins. If it begins too early then the transfer of work from the gas to the piston would be too large. If the combustion starts too late, then the peak pressure in the cylinder is reduced and the expansion work transfer from the gas has decreased [5].

Maximum brake torque timing (MBT) is defined as the spark timing that gives maximum engine torque at a fixed speed [5]. This spark timing also yields maximum brake power and reduced brake specific fuel consumption. It can be seen that MBT depends on speed. As the speed is increased the spark must advance in order to maintain optimum conditions. The operating conditions are also load dependant. As load and intake manifold pressure (IMP) are decreased the spark timing is further advanced to maintain performance [5].

The effect of retarding spark by 80 degrees after top dead centre (ATDC) and advancing spark by 30 degrees has been analyzed in detail [13]. It is known that spark timing affects cylinder pressure and therefore peak burned and unburned gas temperatures. Retarding the spark increases exhaust temperatures, decreases engine efficiency and decreases heat loss [5]. This can be used as a control mechanism for NOx emissions. Increased oxidation in the cylinder and also in the exhaust manifold occur as a result of spark retard.

It was found that spark retardation caused emissions to drop after three seconds of engine start. Advancing the spark caused emissions to increase sharply and then level off. It was also found that HC emissions were reduced by spark retardation regardless of A/F ratio [13]. This is due to enhanced oxidation caused by increased temperatures.

2.3.8 Valve Timing

It can be a very difficult task defining optimum values for valve opening/closing/lift in each operating condition. Different objectives (often conflicting) are being pursued simultaneously such as torque and brake specific fuel consumption (BSFC), improvements in parallel with achieving idling stability or emissions control. In a variable valve timing engine, the intake cam shaft phase changes with engine speed and load (accelerator position).

For lower engine speeds, the inlet valve opening (IVO) is retarded. This improves idling quality and smoothness. In dual intake valve engines, one of the intake valves can be deactivated to enhance combustion stability and burning rate [9]. At moderate rates the inlet valve opens much earlier. This early valve opening boosts the torque and also allows exhaust gas recirculation (EGR) by increased valve overlap time. This results in the reduction of fuel consumption and NOx emissions. The effect of different inlet valve timings on BSFC and NO emissions at constant speed are highlighted in the figures 2.8 and 2.9. It can be seen from the figure 2.8 that altering IVO has significant effects on NO emissions. Comparing an IVO advance of 10° and an IVO retard of 50°, it can be seen from figure 2.9 that NO emissions increases by roughly a factor of 5 for an IVO advance. This is due to the fact that retarding the IVO allows a period of valve overlap to occur, thus enabling EGR. EGR reduces peak cylinder temperatures and output of NO. It has been noted that HC emissions are reduced at medium load and retarded inlet valve opening to exhaust gas re-burning.

2.4 Exhaust gas recirculation (EGR)

EGR is the primary method for control of NOx emissions from SI engines. A fraction of the exhaust gas is re-circulated and mixed with fresh fuel/air mixture in the intake system.

The exhaust gas together with the residual gas from previous combustion cycles forms the total burned gas fraction in the combustion chamber. The burned gas fraction acts as a dilutant within the cylinder [5].

The burned gas fraction in a cylinder is given by the following equation:

$$Xg = Megr + \frac{Mr}{Mc} = \left(\frac{EGR}{100}\right)(1 - Xr) \qquad (2.9)$$

Where,

- **Xr** is the residual gas fraction

- **Megr** is the mass of re-circulated exhaust gas
- **Mr** is the mass of residual gas
- **Mc** is the total mass of gases in the cylinder
- **EGR** is the % EGR (maximum EGR values for SI engines vary from 20% to 30% [5]

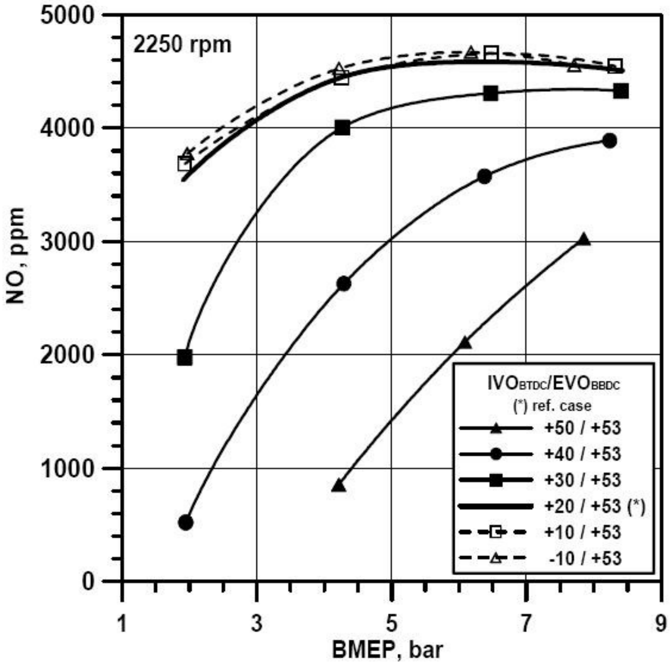


Figure 2.8: Part load NO Emissions at constant speed [15]

The peak combustion temperature is reduced inside the cylinder as the burned gas fraction acts as a dilutant in the unburned mixture. This then yields a reduction in NOx production. The drawback of EGR is that it results in significant increases in the production of HC emissions. This is due to the decreased burn rate and also to the increase in cycle by cycle combustion variations resulting from a leaning of the equivalence ratio.

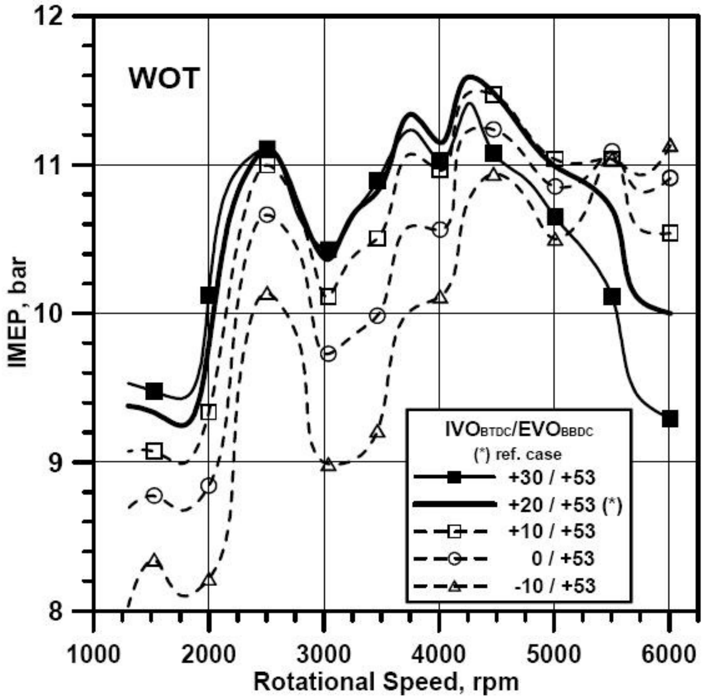


Figure 2.9: Intake Cam Phasing Effects on inlet mean effective pressure (IMEP) [11]

2.5 Engine Load and Speed

A common way of presenting the operating characteristics of an internal combustion engine over a range of speeds is by plotting fuel consumption on a 2-D plane of engine speed and load. Major factors affecting load are wind resistance, tire-roadway friction, acceleration, road gradient, engine friction and the use of accessories such as air conditioning [14].

The effect of speed and load on emissions has been studied in detail. It is clear that NOx emissions increase steadily with increased speed and increase significantly with increasing load. It is evident that as speed and load increases so does the cylinder pressure and temperature. Increased pressure and temperature in the cylinder has the effect of ensuring complete burning of HC but results in a greater rate of NOx formation.

The effect of driving mentality on emissions has also been studied. Driver mentality was categorized into calm, moderate and aggressive modes [15]. Each mode is corresponding with varying acceleration and braking schemes. All modes and tests were performed by the same driver. Aggressive driving resulted in four times the emissions as compared to moderate driving. This result agrees with a similar study that predicted a 200% - 400% increase in NOx emissions for a hard acceleration cycle compared to a constant speed cycle [16]. Compared to moderate driving, HC and CO emissions were reduced with calm driving while NOx remained unchanged [17].

In a study conducted to show the effect of road gradient on emissions it was found that for an uphill road gradient of 3.8%, CO and NOx emission factors nearly doubled, while HC emissions increased by 50% [18]. The idea of emissions of NOx and CO as a function of specific power has been previously studied [14]. Specific power Figure 2.9 is the sum of the external forces opposing vehicle motion multiplied by vehicle speed and divided by vehicle mass. From previous studies, NOx and CO were both seen to increase with increasing specific power.

$$Ps = \frac{Fe.v}{Mv} \quad (2.10)$$

2.6 Air Fuel Ratio

The ratio of air to fuel is a highly essential parameter in defining engine characteristics. In engine tests, the fuel and air flow rates can be directly measured. The fuel flow rate is determined by a metering system which is to compare with the air flow rate of the engine during its operation [5]. The engine characteristics are defined by either the relative air/fuel ratio or the air/fuel equivalence ratio Ø. A lean mixture in relation to spark engines refers to a rich mixture of air, where a rich mixture refers to a rich influx of fuel in comparison to air.

The main contributing factors to emission formation are the concentration of oxygen and the peak operating temperatures within the cylinder. Therefore the air/fuel ratio has a large effect on both these parameters. As can be seen from Figure 2.10 a lean mixture results in high HC emissions due to a lack of oxygen for afterburning of unburned HC [5]. With lean mixtures, HC emissions increase exponentially due to partial burning cycles or even misfire.

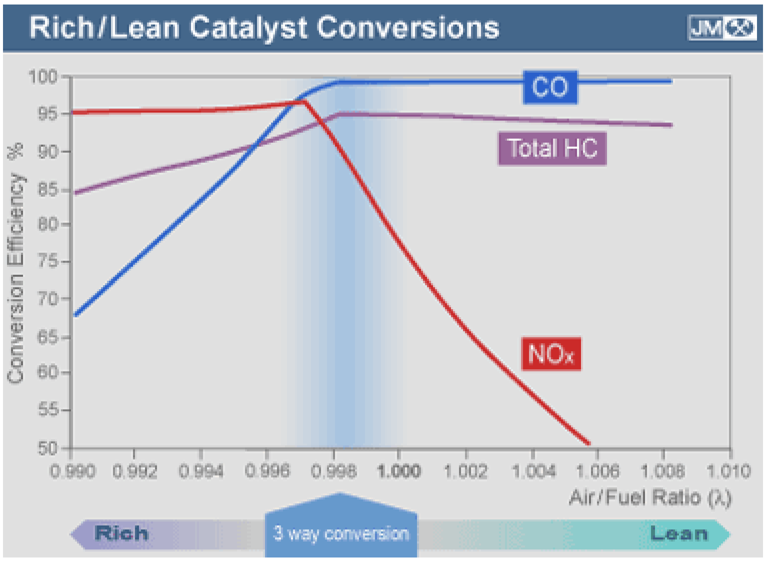


Figure 2.10: Effect of Equivalence Ratio on Spark Ignition Engine Emissions [19]

2.7 Exhaust Gas After-Treatment Systems

Between the exhaust manifold and the silencer of the car exhaust is a system known as a three way catalytic converter. This system helps to oxidize simultaneously CO and HC emissions to CO2 and H2O whilst greatly reducing the NOx into N2 and O2. These processes can only be achieved at air/fuel ratios close to stoichiometric. An exhaust gas oxygen (lambda) sensor is used to control the air fuel ratio. An electronically controlled fuel injection system, operating under "Closed Loop" control is generally employed to this effect.

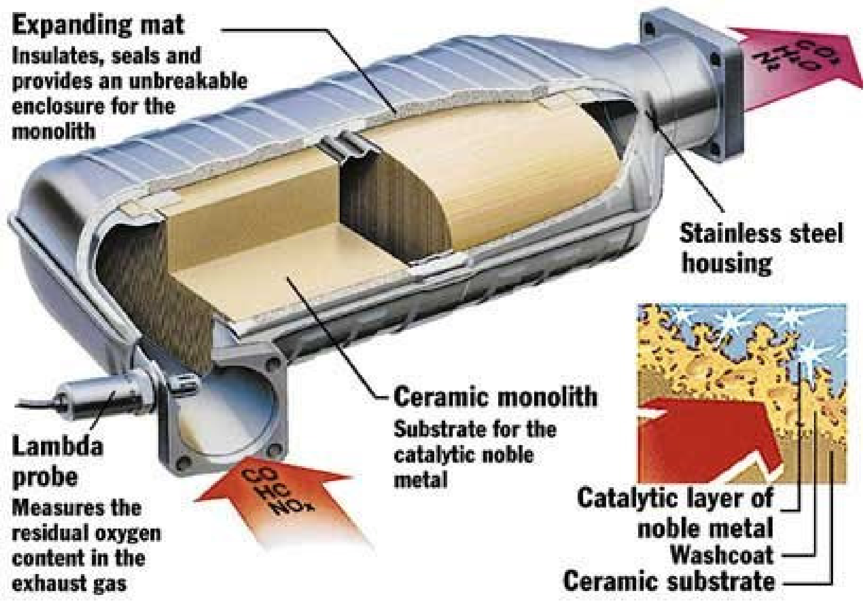


Figure 2.11: Schematic of a Three-Way Catalytic Converter [20]

A catalytic converter Figure 2.11 consists of a chamber where a chemical reaction takes place to convert harmful exhaust gases into less harmful ones. A typical three-way converter converts over 95% of the CO, NOx and HC into CO2, N2 and H2O respectively.

A catalytic converter is made up of stainless steel housing with an inner honeycomb structure of ceramic material. This ceramic material is covered with a coating of aluminium oxide which is then covered with a small amount of platinum and Rhodium. The platinum accelerates the oxidization of CO and HC, whilst rhodium reduces NOx.

The catalytic converter has a minimum operating temperature of about 300°C. At temperatures between 800°C and 1000°C the noble metals (Platinum and Rhodium) begin to breakdown. At temperatures above 1000°C rapid breakdown of the catalyst takes place. Leaded petrol can lead to catalyst poisoning as can excessive oil residue.

2.8 New Emission Devices

2.8.1 Diesel Particulate Filter

A diesel particulate filter (DPF), figure 2.12, is the part of the engine exhaust system responsible for cleaning the engine exhaust gases before they enter the atmosphere. In order to meet the new European emissions legislation it is necessary to find new ways to filter exhaust gases before they leave the vehicle exhaust system. The DPF uses advanced technology in order to reduce exhaust smoke and black soot [21].

In addition to converting harmful exhaust gases (In the same way a conventional catalytic converter works), the DPF collects soot particles emitted by the exhaust gas until a pre-determined level is reached [21]. At this point, the DPF starts the process of cleaning itself, known as DPF regeneration. This process increases the temperature within the DPF (to around 300°C - 350°C) and burns off the soot particles.

In order to carry out the regeneration process, the DPF has to reach and maintain an exhaust temperature higher than its normal operating temperature. Under most conditions the vehicle is able to carry out the regeneration process unaided.
However, in some circumstances where the required temperature cannot be achieved, for example, frequent short journeys or stop start driving, the vehicle may fail to start the DPF Regeneration process. If this situation occurs, the following lamp Figure 2.13 will become illuminated on the dash board.

When the warning light illuminates, it means the vehicle needs help to start the regeneration procedure. This process involves the vehicle being driven in a manner which helps increase the exhaust temperature. If these conditions are not met and the DPF light remains illuminated, it means soot levels are continuing to rise

Once they reach a certain level, the following lights Figure 2.14 will appear together on the dash board.

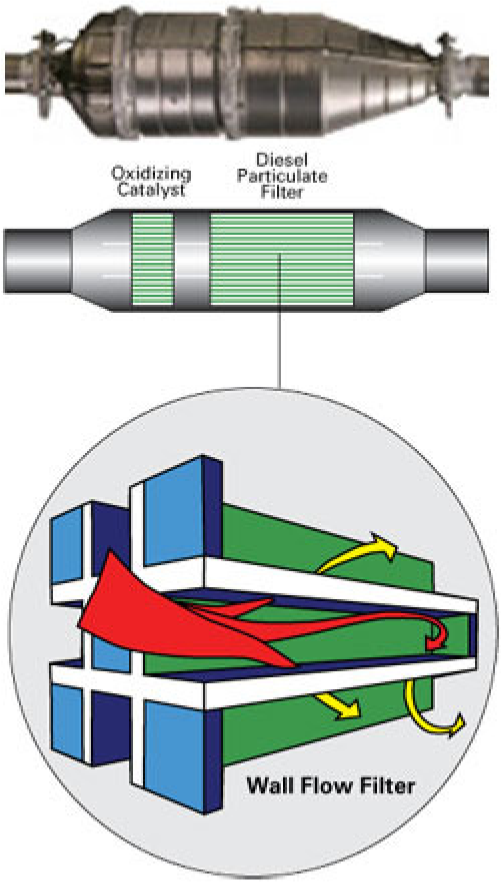


Figure 2.12: Diesel Particulate Filter [22]

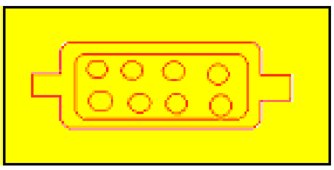


Figure: 2.13: Regeneration indicator.

Figure 2.14: Blocked DPF warning lights [22]

If two or more lights come on together, it is recommended that the vehicle be driven straight to a garage, so that the regeneration procedure can be carried out. Failure to do so may result in reduced engine power, followed by the DPF becoming blocked. If the DPF becomes blocked to the point where it cannot carry out the regeneration process, the DPF will need to be replaced [21].

2.9 Emissions Legislation and Testing

The first European emissions legislation came into effect on the 20/03/1970. This came under the directive 70/220/EEC, which was a set of regulations, test procedures and limits proposed to try control escalating vehicle tailpipe emissions. The USA then introduced similar measures in the same year. The first legislation expressed emissions as a percentage or parts per million (ppm) [9]. Today, concentrations are expressed either as:

1. Light vehicles: mass per unit distance [g/km] or [g/mile]

2. Commercial vehicles: mass per unit of energy produced [g/kWh] or [g/bhp.h]

Light vehicles are generally tested on a chassis dynamometer whereas for commercial vehicles, emission measurements are taken with the engine installed on a test bench. These test procedures can, vary from country to country.

2.9.1 Drive cycle

A driving cycle is a time series of vehicle speeds developed to represent typical driving patterns. They are used intensively in estimating vehicle emissions, computing energy consumption, and assessing traffic impact. So far, there is no existing driving cycle officially developed to represent traffic in Ireland. Researchers in Ireland relied primarily on the European test cycle (ECE) and the New European Driving Cycle (NEDC) to generate emission factors and inventories, which may not be able to produce accurate results because the driving characteristics differ from one area to another. In fact, many studies have been conducted in China [23-24] to identify the differences in vehicle driving patterns between the real situation in China and the standard cycles in other counties. As social, economical, and geographical features vary dramatically throughout the country, the variation in driving patterns in different cities could be significant. China is facing serious air pollution problems, with a large contribution from vehicle emissions.

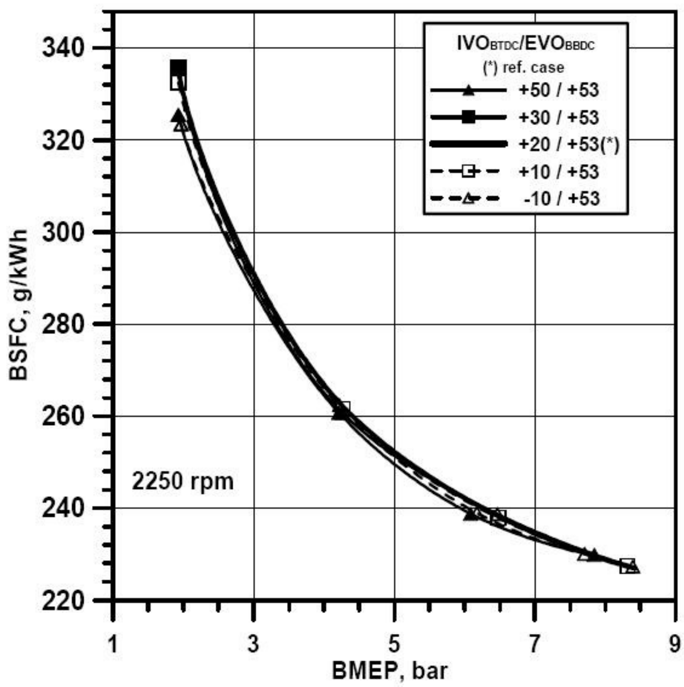


Figure 2.15: Part Load BSFC at constant speed [11]

At high engine speeds, the inlet valve opening is delayed to develop full power. Evidence for this reasoning can be seen in figure 2.15. The dashed lines on the graph represent late IVO whereas the solid lines represent early IVO (with respect to TDC). It is clear that a late IVO yields the highest yield effective pressure (IMEP) at high speeds and wide open throttle.

2.9.2 Urban Cycle and Extra Urban Cycle

The test engine is placed on a chassis dynamometer fitted with load and inertia simulation [25]. Efforts are made to ensure that dynamometer vibrations are minimised so as not to affect the results. The test lasts a total of 1180 s and consists of two parts. Part 1 is comprised of four urban driving cycles while part 2 consists of one extra urban cycle. Table 2.1 presents the operating cycle on a chassis dynamometer of an elementary urban driving cycle. The total time for an elementary urban driving cycle is 195 s. However, for table 2.2 shows the operating cycle on a chassis dynamometer of an extra urban driving cycle. It can be seen that the total time for one extra urban cycle is 400 s.

Table 2.1: Phase breakdown of Urban Drive Cycle

Phase	Time (s)	% Total
Idling	60	30.5
Idling, moving vehicle, clutch engaged	9	4.6
Gear Change	8	4.1
Acceleration	36	18.5
Steady Speed	57	29.2
Deceleration	25	12.8
Total	195	100

Table 2.2: Phase Breakdown of Extra Urban Drive Cycle

Phase	Time (s)	% Total
Idling	20	5
Idling, moving vehicle, clutch engaged	20	5
Gear Change	6	1.5
Acceleration	103	25.8
Steady Speed	209	52.2
Deceleration	42	10.5
Total	400	100

This Driving Cycle is designed to model real on-road city driving patterns. The cycle exhibits low vehicle speed, low engine load and low exhaust gas temperatures. The new NEDC drive cycle shows complete Urban Cycle and Extra-Urban, Figure 2.16.

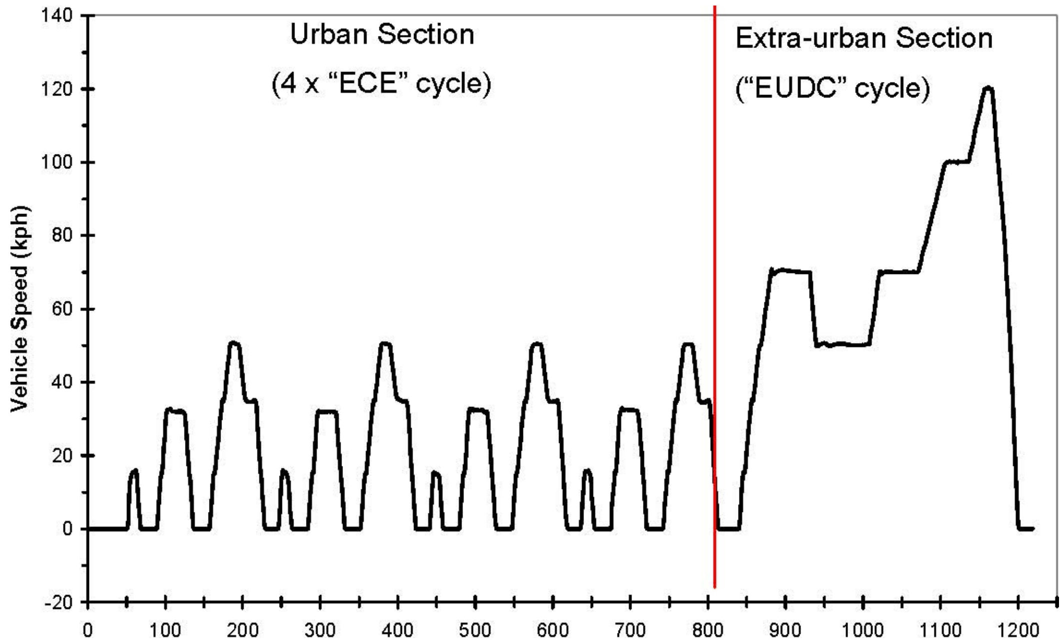


Figure 2.16: Implementation of the NEDC drive cycle

Modelling a real on-road driving pattern accurately is extremely complex as the emissions obtained from these tests are estimates. Some researchers found these result unrepresentative [26], but the results are still accepted as the standard test in Europe.

2.9.3 EU Emissions Testing

The EU has defined seven emission tests to be carried out. A certain number of these tests (depending on engine type in terms of spark ignition or compression ignition) must be carried out on all new vehicles entering the market.

A list of all of the legislated emissions tests is provided:

1. Verification of average tailpipe emissions after a cold start
2. CO emissions at idling
3. Emissions of crankcase gases
4. Evaporative emissions test
5. Durability of antipollution devices test
6. Verification of average low ambient temperature CO and HC emissions after cold start.
7. OBD test

Spark ignition engines must undergo all of these tests whereas compression ignition must undergo test 1, 5 and 7 where applicable [9].

2.10 Threshold Emissions

Automotive vehicles contribute highly to poor air quality through emitted engine gases. Poor air quality has a negative effect on the surrounding environment and can also lead to cardiovascular disease and respiratory problems. In order to maintain good air quality, newly manufactured vehicles must meet national emissions standards.

2.10.1 Cars and Light Vehicles (<2500kg)

In 1993, an emission standard for cars and light vehicles called the “Euro” standard was introduced across the EU. The aim of this standard was to curb the amount of on-road vehicle emissions and to preserve air quality. Since 1993, successive Euro standards have been introduced. In January 2005, the Euro 4 standard was introduced across the continent. An overview of the limits set for NOx, PM and HC by the successive Euro standards is shown in table 2.3 for petrol engines.

So far Euro 5 was introduced in 2009 and the Euro 6 regulations are due in 2014. The original aim of the European commission was the introduction of the Euro 5 by mid 2008. The introduction was delayed to give manufacturers sufficient time to test and build the new cars.

Table 2.3: Euro limits [2]

Tier	Date	CO	THC	NMHC	NO_x	$HC+NO_x$	PM
Petrol (Gasoline)							
Euro 1	July 1992	2.72(3.16)	-	-		0.97 (1.13)	-
Euro 2	January 1996	2.2	-	-		0.5	-
Euro 3	January 2000	2.3	0.20	-	0.15	-	-
Euro 4	January 2005	1.0	0.10	-	0.08	-	-
Euro 5	September2009	1.000	0.100	0.068	0.060	-	0.005**
Euro 6 (future)	September 2014	1.000	0.100	0.068	0.060	-	0.005**

The Euro 5 standards aim to further restrict the harmful emissions of CO, NOx HC and particulate matter (PM). It is hoped that it will serve to close current loopholes for heavy sports utility vehicles (SUV) and four wheel drive vehicles which exist under Euro 4. Euro 5 also aims to significantly close the gap between petrol and diesel engines for the emissions of both NOx and PM.

Starting from the Euro 3 stage it had been compulsory for all vehicles to be equipped with an On-Board Diagnostic (OBD) system for the purpose of emissions control. Legislation stipulates that the driver must be notified of any deterioration of the emission related parameters which could cause emissions to exceed the mandatory thresholds as described in table 2.4.

Table 2.4: Overview of Euro OBD Threshold limits g/km [27]

Category	Class	Tier*	Date	CO	HC	NO_x	PM
Diesel							
M_1		EU 3	2003	3.20	0.40	1.20	0.18
		EU 4	2005	3.20	0.40	1.20	0.18
N_1	I	EU 3	2005	3.20	0.40	1.20	0.18
		EU 4	2005	3.20	0.40	1.20	0.18
	II	EU 3	2006	4.00	0.50	1.60	0.23
		EU 4	2006	4.00	0.50	1.60	0.23
	III	EU 3	2006	4.80	0.60	1.90	0.28
		EU 4	2006	4.80	0.60	1.90	0.28
Petrol (Gasoline)							
M_1		EU 3	2000	3.20	0.40	0.60	-
		EU 4	2005	1.90	0.30	0.53	-
N_1	I	EU 3	2000	3.20	0.40	0.60	-
		EU 4	2005	1.90	0.30	0.53	-
	II	EU 3	2001	5.80	0.50	0.70	-
		EU 4	2005	3.44	0.38	0.62	-
	III	EU 3	2001	7.30	0.60	0.80	-
		EU 4	2005	4.35	0.47	0.70	-
Note: Passenger cars category M_1 > 2,500 kg or with more than 6 seats meet OBD requirements for Category N_1.							

To distinguish between the US OBD, the European limits are referred to as the EOBD (European OBD). The thresholds are based on the NEDC test.

2.10.2 Heavy Duty Vehicles

It is important to note that regulations for heavy duty engine vehicles are covered by separate legislation to cars and light vehicles. Heavy duty vehicle emissions regulations were originally introduced in directive 88/77/EEC, which has been subsequently amended on numerous occasions.

European Union emission regulations for heavy duty vehicles are commonly referred to as Euro I....V. It is convention to use Roman numerals when referring to Heavy duty vehicle regulations [8]. Arabic numerals are used for cars and light duty vehicles. Table 2.5 below gives a summary of emissions limits (g/whir) for vehicles for approval on the European market.

Table 2.5: Overview of Euro Standards for Heavy-Duty Vehicles [27]

Tier	Date	Test	CO	HC	NOx	PM	Smoke
Euro I	1992, < 85 kW	ECE R49	4.5	1.1	8.0	0.612	
	1992, > 85 kW		4.5	1.1	8.0	0.36	
Euro II	1996.10		4.0	1.1	7.0	0.25	
	1998.10		4.0	1.1	7.0	0.15	
Euro III	1999.10, Eves only	ESC&ELR	1.5	0.25	2.0	0.02	0.15
	2000.10	ESC&ELR	2.1	0.66	5.0	0.10 0.13*	0.8
Euro IV	2005.10		1.5	0.46	3.5	0.02	0.5
Euro V	2008.10		1.5	0.46	2.0	0.02	0.5

* for engines of less than 0.75 dm^3 swept volume per cylinder and a rated power speed of more than 3000 min^{-1}

2.11 Emission Calculation Models and Databases

Models for emissions and fuel consumption factor estimations can be broadly divided into two categories.

- Average Speed Model
- Instantaneous Emission Model

2.11.1 Average Speed Model

The average speed approach is commonly used to estimate emissions from road traffic. This approach is based on aggregated emission data for various driving patterns. Driving patterns are represented by their mean speeds alone [28]. The average speed, vehicle class, size and year are used to obtain a derived speed emission function. This function fails to take into account that different cycles (i.e. with different driving behaviours and vehicle dynamics) with the same average speed will obtain different emissions and fuel consumption factors [29]. This approach is limited to regional and national estimates [28].

The MODEM project, in an attempt to overcome the average speed model limitations, established a set of 14 realistic driving cycles from a set of on-street measurement exercises [30]. Emission data for the 14 cycles was then obtained from a range of vehicles using chassis dynamometer tests. A set of charts relating the emissions CO, HC, NOx and CO2 and fuel consumption to second by second speeds for the driving cycles were then produced.

2.11.2 Instantaneous Emissions Model

The use of instantaneous emission models was introduced to overcome the limitations of the average speed model. This model measures emissions continuously at the exhaust during chassis dynamometer tests and stores the data at a particular time interval (typically 1 s) [28]. An averaged emission value is assigned to every pair of instantaneous speed and acceleration values (measured simultaneously). The emission function can then be defined as a two dimensional matrix of speed and a product of speed and acceleration. Figure 2.17 details a NOx emission matrix for a spark ignition engine test cycle. This modal method still has limitations in estimating transient, high acceleration emissions due to the fact that these matrices are derived solely from chassis dynamometer tests [29].

2.12 Comparison of vehicle emissions measurement technique

Regulatory testing, figure 2.17, includes a pre-scale vehicle certification testing as manufacturer should proof their vehicles to be under emissions standards (type approval tests) which are being done on chassis dynamometer emissions test equipment.

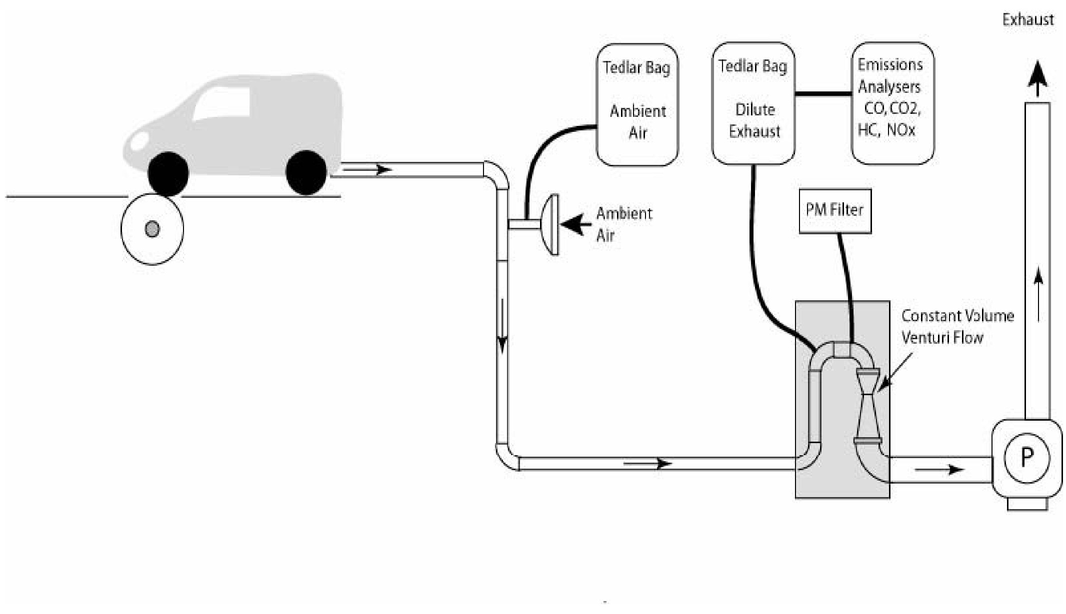


Figure 2.17: chassis dynamometer emissions test equipment [16]

Another procedure is in-service inspection and maintenance. This procedure is an idle test used without load applied to the engine where a gas analyzer probe is inserted into the tailpipe to measure the concentration of vehicle emissions [31]. Sometimes, a load can be applied to the engine for more representative measurements [32], but that may lead to excessive costs [27]. Present built-in on-board diagnostic (OBD) systems can identify faulty parts in the car [33].

In terms of on-road emission monitoring, there are two types of emission tests:

1. **Monitoring equipment:** Used to measure the emission concentrations in ambient air [34], this type uses a pump to sample the ambient air and sometimes samples of PM or HC emissions collected and analyzed in a laboratory [35]. This type of technique is being considered to be good in measuring the in-use vehicle fleet rather than single vehicles measurements [36]. One of their applications is in Tunnel studies, where this equipment is placed inside the tunnel in order to measure the emissions factors for CO, CO2, NOx, and HC [37].

2. **On-road remote sensing:** Used where some tools, figure 2.18, set up on a roadside to measure the emissions from a single car when it passes [38]. These tools have been developed by researchers for a better understanding of emission factors CO, NO, HC and PM [39 -41]. On-road remote sensing was successfully used in many regions to specify vehicle fleet emissions [42-44]. Fuel consumption has been improved for emissions factors using this technique [45]. However, there is no direct method to determine the details of the mode of operation such as gear, engine speed, etc at the moment of measurement [46].

Results from regulatory measurements methods are not sufficient. Chassis dynamometer testing must be carried out [47]. Chassis testing can be done in parallel by either instantaneous or modal emissions with the aggregate bag measurements required for certification [48].

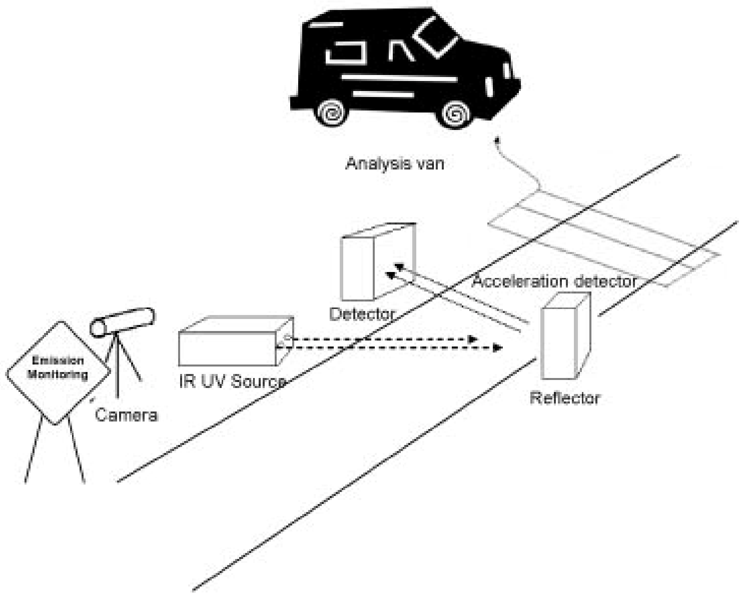


Figure 2.18: Equipment for remote sensing of vehicle emissions [49]

Using drive cycles in chassis dynamometer testing is not always representative of real drive cycles [50-52]. Its use only covers a limited area of driving modes [53]. Because of this, much research has been carried out in developing realistic driving cycles. Comparison between these drive cycles showed differences in measured emissions, [54-55]. Since using the on-board emission monitoring for measuring instantaneous emissions makes data acquisition relatively quick, cost of testing is reduced and allows the drive cycles and emission factors to be evaluated [56-59]. Correlation between measured and estimated emissions was found to be within 5% for CO2 and NOx [60] and within 10% for HC and CO [61]. Much research has been done using emission analyzers in order to calculate the instantaneous emissions. For example, Ayala et al identified the different hydrocarbon species emitted from the tailpipe [62].

As it was mentioned previously, vehicle emission estimation done on a single car needed to be validated by using measuring equipment fitted to the car tested [63-64]. One of the parameters has been found to affect emissions levels is driver behaviour [65-66].

Table 2.6: Comparison of vehicle emissions measurement technique

Measurement type	Vehicle operation			Emissions measurement		Comments
	Known	Repeatable	Representative	Units	Resolution	
Unloaded tailpipe test	Yes	Yes	Poor	Concentration	Pass/Fail	Fleet-wide test program, however, numerical data not archived
On-board Diagnostics (OBD)	Yes	No	Good	Relative to expected	Pass/Fail	NO quantitative data recorded
Ambient	No	No	Good	Mass per unit time , Per unit traffic	Low	Develop fleet average emission factors
On-road remote sensing (RS)	Possibly	No	Good	Mass emission per unit mass fuel	Good	Individual vehicle data may be recorded, but vehicle operating state unknown
Engine Dynamometer	Yes	Yes	Poor	Mass per unit time	Excellent	Simplified duty cycles to test engine performance .Loads difficult to simulate
Chassis Dynamometer	Yes	Yes	Moderate	Mass per unit time	Excellent	Detailed and representative measurements, good repeatability, but testing expensive
On-Board, in-use	Yes	Moderate	Good	Mass per unit time	Good	Detailed and highly representative, Difficult to reproduce test conditions

Traffic jams have also been studied as one of the parameters that affect emission levels [67-68]. Table 2.6 shows a Comparison of vehicle emissions measurement techniques.

2.13 Comparison of vehicle emissions modeling technique

Many modeling methods have been developed in estimating the emission factors in transport sector [69-70]. National emissions inventories in areas (such as a country or a state) are important to assess the emissions levels, identify the air quality and help reduce the hazardous emissions affecting human health and environment.

Studies has been done in developing these modeling methods to estimate the emission factors CO, CO2, HC, NOx and PM [69]. This study also investigated other factors such as evaporative emissions and PM emissions of brake dust [70]. The standard method in Europe and US is the average-speed models. The most useful data set for the work carried out for this thesis is COPERT (Computer Programme to estimate Emissions from Road Transport) [71] or the TRL (Transport Research Laboratory) emissions factors. Both can describe emissions in terms of grams per kilometer travelled [g/km] and are functions of vehicle speed [72], such that for the TRL factors:

$$EFi\,,m\,,n = k + ax + bx^{2} + cx^{3} + \frac{d}{x} + \frac{e}{x^{2}} + \frac{f}{x^{3}} \quad (2.11)$$

- Where a, b, c, d, e, f and k are coefficients specific to a given engine size, m and technology level, n,
- x is the average vehicle speed in kilometres per hour (g/km)

- EFi, m, n is the emissions value, in grams per kilometre travelled (g/km) for a given species i, of age m and engine size, n.

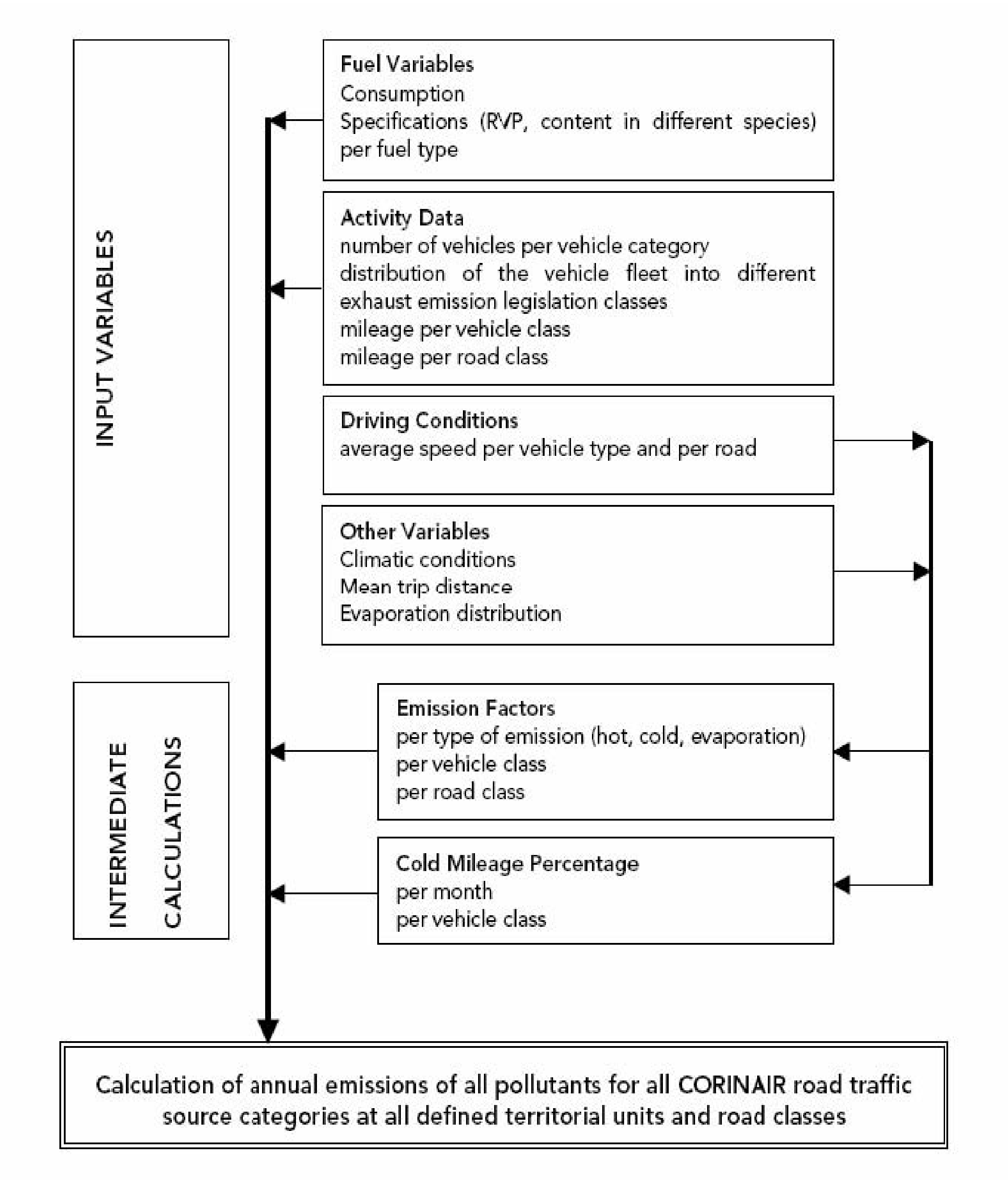


Figure 2.19: The COPERT III baseline methodology [71]

Emissions calculations exist for each of carbon dioxide (CO2), carbon monoxide (CO), particulate matter (PM), oxides of nitrogen (NOx) and unburned hydrocarbons (HC) [50].

A similar equation exists for the COPERT model and it will be discussed in the following chapter. Figure 2.19 shows the COPERT baseline methodology. COPERT4.V9 has recently been made available [73].

Validation studies for COPERT as well as method comparison studies are still on-going. Ekstrom et al found an agreement in NOx emissions between COPERT and on-road sensing measurements, while a weaker agreement was noticed for CO and HC (COPERT was overestimated) [74]. Another programme MOBILE6 has been compared with on-road sensing measurements. Noticeable differences have been found between the two methods [75]. Smit et al introduced a new modelling approach for road traffic emissions: VERSIT+. When compared to COPERT, higher accuracy was noticed with VERSIT+ with respect to emission estimations [76].

Although average-speed models have a world-wide use in transport sector, there are some difficulties facing this method. Difficulties include fleet test data, fleet activity patterns, acceleration issues and identifying of local emissions [47]. However, good correlations between the predicted results of the modelling packages and the actual data obtained by direct measurement are still maintained.

Chapter 3 Experimental Study

3.1 Introduction

The transport sector is one of the major contributors of hazardous emissions to the environment in recent years. In 2005 40% of NOx emissions (about 119kt) and 25.6% of CO2 emissions (about 55.6 Mt) originated from the transport sector in Ireland [77]. Various approaches to help decrease these emissions by; using new technologies, where fuel consumption has been minimized using dynamic optimization [26]; applying new legislation standards for newer cars; using alternative fuel systems, such as using liquefied natural gas or bio-fuels in heavy duty vehicles [78-80]; applying new strategies, such as a road transport system based on renewable resources [81], or developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption, had proposed [82]. Moreover, the design of 100% renewable energy systems has been discussed in literature with the analyzes and results that includes the transport sector [83].

Since emission estimation from road transport can assist researchers in evaluating the air quality in urban areas, many projects have validated modelling methods in order to represent accurate results [84]. Car testing includes pre-test vehicle certification using chassis dynamometer emissions test equipment as manufacturers must prove that their vehicles comply to emissions standards (type approval tests) [85], thus making the vehicle valid in terms of emission limitations over a period of time. Thereafter, a vehicle should pass a compulsory vehicle inspection test in order to ensure that the vehicle's emissions are under a certain limit.

This chapter provides information on the experimental work, details of the testing steps, the equipment used and the characterisation of the trips chosen. The first section of this chapter describes the preparation of the testing. Also in the first section, equipment and its use are clarified. The last section of this chapter provides information on where data is obtained and how the data is exploited. Results from regulatory measurement methods are not sufficient, and chassis dynamometer testing must be carried out. This can be done by either instantaneous or model emissions in parallel with the aggregate bag measurements required for certification [48].

As it has been discussed in the previous chapter, using limited number of driving modes is not representative. In addition, vehicles could conceivably be tested differently depending on their performance levels and usage characteristics [86]. In this regard, many researchers have developed real-world driving cycles [54 and 87] and compared its differences in measured emissions. Using on-board emission monitoring for measuring instantaneous emissions provides data quickly, reducing the cost of testing and providing the driving cycles and emission factors to be evaluated [56-59]. Comparisons between measured and estimated emission data have been found to be within 5% for carbon dioxide (CO_2) and nitrous oxide (NOx) [60], and within 10% for hydrocarbon (HC) and carbon monoxide (CO) [61].

In conjunction with recent advancements, many software packages have been utilized to estimate vehicle emissions. The advantages of using these software techniques include cost and time savings. Good correlations between the predicted results of the software packages and the actual data obtained by direct measurement are still maintained. In order to estimate vehicle emissions, driving cycles in a city are analyzed by researchers using the same approach in many other countries. Many projects have been conducted to establish the drive cycle of a specific area/city. When validating these estimates, significant differences between measured and modeled emission rates have been found [74]. Sometimes, tunnel studies have been conducted in order to validate the emission estimations [37]. In Edinburgh, for instance, the driving cycle was obtained from recorded data in actual traffic conditions, using the car chase technique, and compared with the European driving cycle [52]. In Athens, emissions and fuel consumption measurements showed significant variations between Athens driving cycle and the European driving cycles [88]. Outside of Europe in Hong Kong, a systematic and practical method for developing representative driving cycles has been developed with focusing on cost effectiveness for continuous refinement of the driving cycle [89].

Some research has been done using emission analyzers in order to calculate the instantaneous emissions. For example, Ayala et al. identified the different hydrocarbon species emitted from the tailpipe [62]. In some of the following experiments, a gas analyzer has been used in order to evaluate the results obtained from the calculated method. The possibility of finding the correlations between the experimental and calculated results is also discussed.

3.2 Research equipment

Quantifying vehicle emission factors was the main objective of this research. A common method involves the use of gas analyzers which measure resultant emissions directly from the exhaust manifold. Such equipment is generally expensive, difficult to calibrate and rather bulky. Therefore, research was concentrated on reliable low cost equipment to understand and facilitate vehicles emission estimation in developing counties.

Firstly, the OBD reader is addressed in terms of its function and instruction of use. Also the corresponding software package built in a LabVIEW, (Laboratory Virtual Instrument Engineering Workbench) is clarified. Secondly, COPERT software is addressed in terms of its evolution of previous versions as well as the current version used. Finally, the gas analyzer that had been used for verification is explained in detail.

3.2.1 OBD reader

The OBD is defined as a "system for emission control which must have the capability of identifying the likely area of malfunction means of fault codes stored in computer memory" [17].

A system for on-board diagnostics was approved by the California Air Resources Board (CARB) and the Environmental Protection agency (EPA) in 1989. This design was adapted by a solution previously proposed by the society of Automotive Engineer (SAE) in 1988 [3]. The aims of the project were twofold:

1. To improve in-use emission compliance by alerting vehicle operators when a malfunction exists.

2. To aid automobile repair technicians in identifying and repairing circuits in emissions control systems [90].

The primary features of the OBD II are:

1. Malfunction Indicator Light (MIL)
2. Diagnostic Trouble Code (DTC)
3. System Monitoring

1. Malfunction Indicator Light (MIL)

An illuminated non-red LED signals a malfunction being detected by the OBD, [22]. A malfunction in the context of OBD is a failure of an emission-related component [17].

2. Diagnostic Trouble Code (DTC)

When a malfunction has been detected, a DTC is stored in the Engine Control Management (ECM) [90]. Each individual malfunction has a corresponding DTC. This enables automotive technicians to efficiently rectify problems associated with the malfunction.

3. System Monitoring

The OBD is required by CARB to monitor all major engine sensors, the fuel metering system and the exhaust gas recirculation (EGR) system as a minimum. It is necessary to note that OBDII is the working name adopted in the USA, whereas EOBD (European On-Board Diagnostics) is the working name adopted in Europe. The OBD proved effective to an extent but there was a need for more dynamic monitoring of the efficiency of the emissions control system [90]. From 1994 to 1996, CARB introduced the second generation of OBD, referred to as OBD II. Although OBD had been available in Europe, EOBD was not standardised until Jan 1 2001 [91].

The following is a list detailing the major OBDII/EOBD features:

- Continuous Monitor and “Once per trip” tests
- Enhanced Oxygen Sensors
- Enhanced Fuel Trim Sensors
- Engine Misfire Detection
- Catalyst Efficiency Monitoring
- Exhaust Gas Recirculation Monitor
- Secondary Air Monitor
- Standardisation of DTC and data streams
- Scan Tools

Another important feature of OBDII is the freeze frame. When a DTC is stored in the ECU, a retrievable serial data freeze frame is also stored along with it [90]. Engine conditions at the time of the DTC being recorded, such as the state of fuel control, spark timing; RPM, load, and warm-up status are stored [92]. This data is accessible using a diagnostic tool. It is important to note that OBD does not directly measure emissions. OBD monitors the vehicle emission control systems to detect malfunctions that could give rise to tailpipe emissions being greater than the legislated limits.

3.2.2 Communicating with the OBD

The OBD-II data line is a bi-directional circuit communication link that is capable of transmitting and receiving data. This allows the user to operate system sensors and sends commands to the engine control unit (ECU) while at the same time displaying system data.

Figure 3.1: ElmScan 5 USB model

The hardware link between the computer and the OBD used in this project is a commercially available ElmScan 5 USB model figure 3.1. This circuit contains an ELM327 chip that converts between the OBD data format and the standard RS232 serial data format. Using this circuit enables any personal computer to communicate with the vehicle using only a free serial port and a terminal program. ElmScan 5 supports the ISO15765-4 and ISO14230-4 protocols. ISO9141-2 and ISO14230-4 protocols are the European and Asian standards. This means that the ElmScan 5 is able to communicate with the majority of OBD enable European vehicles. Table 3.1 has all Technical Specifications of the device.

Elmscan 5 was connected via the OBD socket located within the vehicle. The diagnostic link connector (DLC) socket, which is `D'-shaped, has 16 pins, as it seen in Figure 3.2

Table 3.1: Technical Specifications of Elmscan 5

Processor:	Genuine ELM327
OBDII Protocols:	• ISO15765-4 (CAN) • ISO14230-4 (Keyword Protocol 2000) • ISO9141-2 • J1850 VPW • J1850 PWM
Output protocol:	USB Virtual COM Port
Baud rate:	9600 or 38400
Indicator LEDs:	OBD Tx/Rx, RS232 Tx/Rx, Power
Operating voltage:	12V, internal protection from short circuits /overvoltage
Dimensions:	3.75" x 1.7" (95 mm x 43 mm)

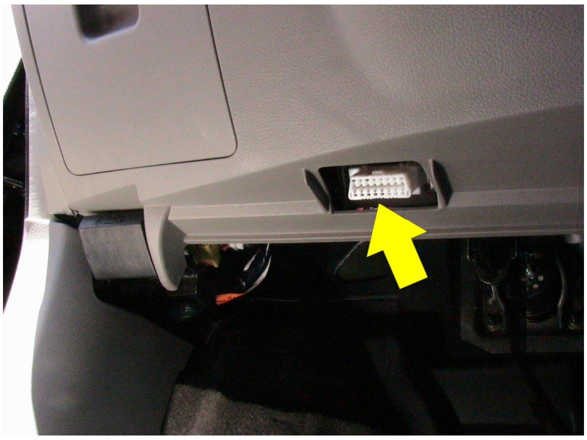


Figure 3.2: OBD socket located within the vehicle

The software provided with OBD reader can show a lot of engine specifications such as absolute throttle position, engine RPM, air flow rate among others as in figure 3.3. Vehicle speed, one of the important data for research interest was also provided in this software but the problem was in logging these data second by second and saving them in an accessible spread datasheet. Therefore, a built in data acquisition software was required. More details about the software will be described in section 3.3.

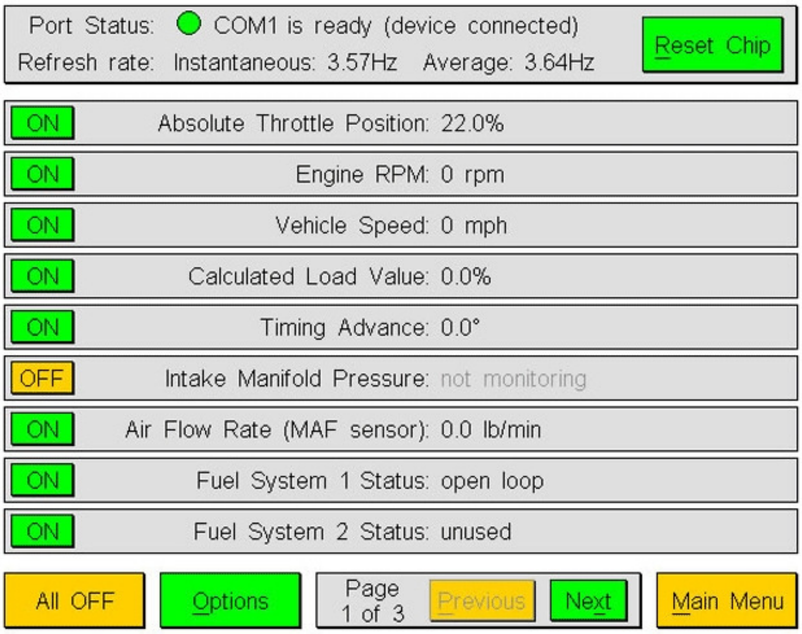


Figure 3.3: Elm Scan 5 communicator [3]

3.2.3 Establishing Communication

To setup the OBD, a Hyper-terminal was needed for setup; this was done using a Microsoft Windows program (Hyper-terminal) on a laptop. The Hyper-terminal is designed to emulate various different data terminals. The Hyper-terminal can be configured to make a connection via a modem or a serial port. Many serial parameters such as baud rate and stop bits are configurable through the hyper-terminal. The necessary values for these parameters are defined by the datasheet.

The data is taken in a hexadecimal form when retrieving or sending data to the OBD. In general, commands sent are of the form OX YZ, where OX refers to the test mode and YZ is the parameter identification number (PID). Responses are generally of the form 4X YZ A B, where 4X denotes a response: YZ is the vehicle parameter of interest and A B is the hexadecimal bytes for the parameter value. Figure 3.4 provides a screen shot of some of the commands sent and the responses received through the Hyper-Terminal.

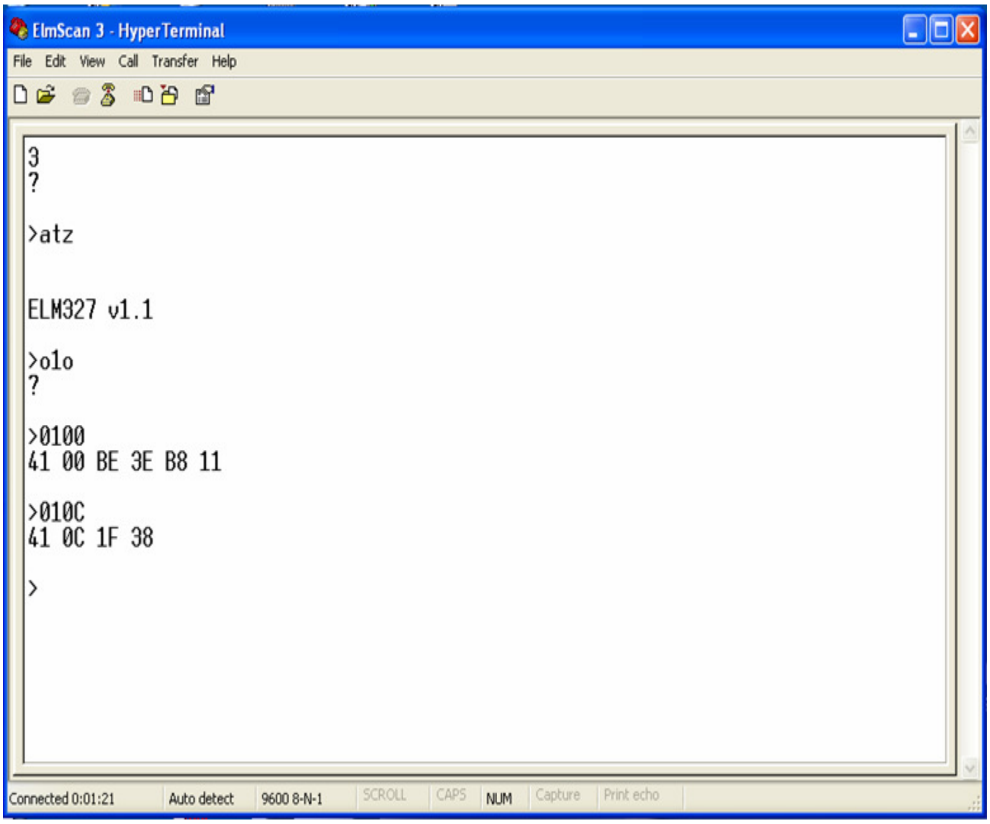


Figure 3.4: Screenshot of Initial Communication with HyperTerminal

Table 3.2: OBD Diagnostic Test Modes

01	Show Current Data
02	Show Freeze Frame Data
03	Show Diagnostic Trouble Cods
04	Clear Trouble Codes and Stored Values
05	Test Results , Oxygen Sensors
06	Test Results , Non-Continuously Monitored
07	Test Results , Continuously Monitored
08	Special Control Mode
09	Request Vehicle Information

The SAEj1979 [93] defines 9 test modes. These are all supported by many vehicles today. These 9 test modes are shown in Table 3.2. This standard also defines a list of PIDs which are used for attaining the appropriate engine parameter values. All of these PIDs can be seen in Appendix (A) [94].

3.2.4 Parsing OBD Data

For the OBD's data to be displayed in a familiar form there is a certain amount of post processing to be done. In the SAE standards there is a defined set of scaling factors to be applied to data received from the OBD which are shown in the Appendix (A) [94].

Parsed data are:

Engine speed (rpm)

- Command: 01 0C
- Response: 41 0C 1F 38

The response can be broken down as follows:

- 41 : Mode response
- 0C: PID 0C (engine speed (rpm))
- 1F 38: Hexadecimal bytes for engine rpm.

The scaling factor for engine speed as defined by the SAE standards is ((A*256) +B)/4. Applying this to the received value for engine speed we get:

$$\frac{(31*256)+56}{4} = 1998 \text{ rpm}$$

Calculated Engine Load Value (%):

- Command: 01 04
- Response: 41 04

Once again the response can be broken down as:

- 41: Mode response
- 04: PID (Calculated engine load value)
- 38: Hexadecimal byte for calculated engine load value

The SAE standards define the scaling factor for calculated engine load as (A*(100/255)) [34]. The formula applied to the data received for calculated engine load value returns:

$$\frac{56*100}{255} = 21.96\%$$

The calculated load value i.e. Load% (PID 01 04), has two definitions, the most common of which is

$$Load\% = \left(\frac{Current\_Airflow}{Peak\_Airflow}\right) \times \left(\frac{BARO @ Sea\_Level}{BARO}\right) \times 100 \tag{3.1}$$

While the definition to be adopted as a standard is

$$Load\% = \left\{\frac{Current\_Airflow}{Peak\_Airflow\_WOT @ STP(RPM) \times (BARO/29.92) SQRT[AAT+273]}\right\} \times 100$$

(3.2)

Where

BARO=Barometric Pressure

AAT= Ambient Air Temperature

The characteristics of the last definition as defined by reviewed literature [95] are:

- It reaches 100 at WOT for any altitude, temperature and pressure or rotational speed for both naturally aspirated and boosted engines
- It indicates a percentage of peak available torque
- It is linearly correlated with engine vacuum
- It is often used to schedule fuel enrichment
- Compression ignition engines can support this parameter using fuel flow in the place of air flow in the above calculation

3.3 LabVIEW Implementation Model

As the commercial software supplied with the OBD reader does not have the ability to save data logged from the car, a special data acquisition package was required in order to save data in an easy interface file to be accessible via Microsoft office Excel. This model was implemented in LabVIEW tool which is a software package, from National instruments, that can be used with an appropriate programming language to fulfil this need. LabVIEW is a platform and development environment for a visual programming language and is commonly used for data acquisition, and industrial automations on a variety of platforms including Microsoft Windows, and MAC. A range of virtual instruments (VIs) capable of performing an extensive range of function are available within the LabVIEW programme.

The LabVIEW implementation of the emissions model was written in four different modules. Writing the model in such a way ensured that each individual module of the overall programme was functioning correctly, prior to interfacing the individual modules with each other, to create the overall programme. The different modules written included an instantaneous emissions model module, a cold start function module, a data parsing module and a serial communication module.

3.3.1 Previous Work

Previous final year studies had attempted to automate an emissions model within LabVIEW, with varying degrees of success [94]. After many attempts in trying to debug previous software it was decided to re-write the LabVIEW implementation, while using previous software as a blueprint for any further development. Re-writing previous programmes enabled testing and validation of the individual modules of the overall programmes and also served to highlight flaws within already developed software.

3.3.2 Instantaneous Emissions Estimation Model Module

In order to successfully implement the instantaneous emissions estimation model, a module was required which used engine speed and engine load as input values. It was envisaged that these values would be used to look up the two-dimensional emissions maps stored on the computer memory as a comma-separated variable file (CSF).

It was decided to use a piece of code specifically developed by a LabVIEW technician. The piece of code in question was a bilinear interpolation function which took in two parameters and used these parameters to search a two-dimensional array (i.e. the emissions maps). On attaining the piece of code which suited the required need, it was necessary to write a sub-module which ensured that the array indices search correlated directly to the data input. This was achieved through a simple Excel analysis. The calculation of the indexing function for engine speed is shown in table 3.3 and figure 3.5. The same method was used for calculation of the indexing function for engine load.

Table 3.3 Engine Speed Array Indexing

Engine Speed (rpm)	Array Index
0	0
1000	1
1250	1250

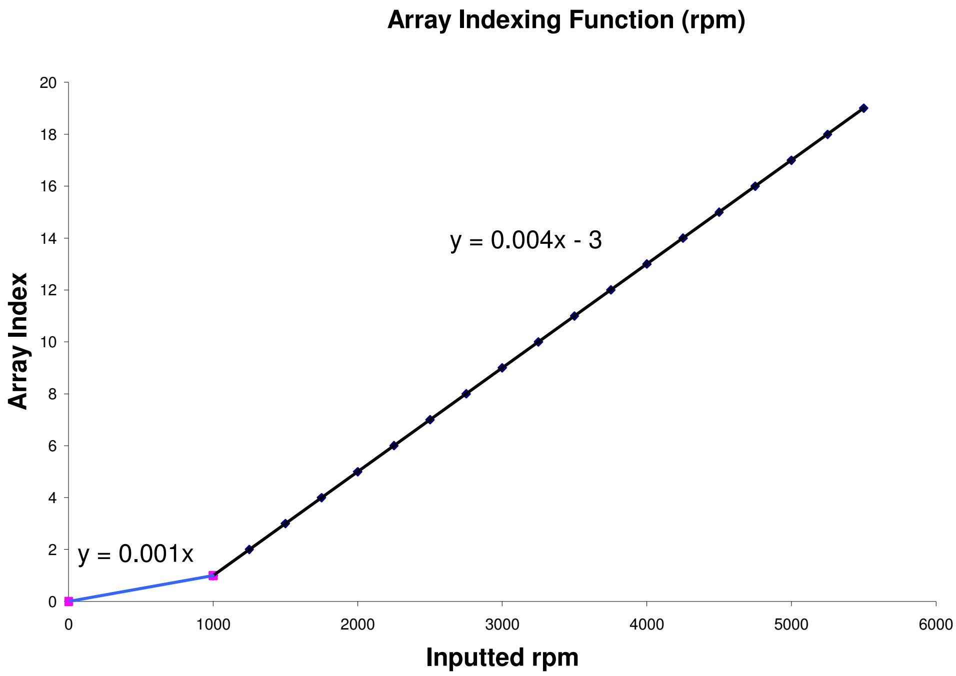


Figure 3.5: Array Indexing Scaling Equations

The formulae shown on the graph in figure 3.5 are an indication of how the received data for engine speed needed to be scaled before it was input into the bilinear interpolation function. A block diagram of the LabVIEW implementation of the indexing sub-modules is shown in figure 3.6. Using the case structure VI available within LabVIEW, it was possible to ensure that the inputted parameter was scaled correctly depending on its value.

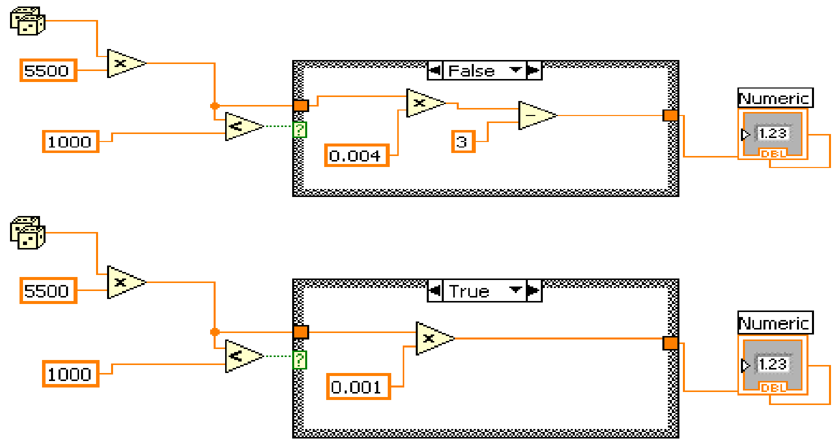


Figure 3.6: LabVIEW Implementation of Array Indexing Sub-Module

Having ascertained that the bilinear interpolation VI was functioning correctly, it was then implemented four times within a "while loop", to search the individual emissions, and fuel consumption maps for instantaneous emissions and fuel consumption values. The values attained for instantaneous emissions, and fuel consumption was then passed through a shift register. The purpose of the shift register was to sum the instantaneous emissions values and give an estimate of emissions as a function of a particular trip. Finally, a graphical user interface for the emissions model was formed using the control VIs available within LabVIEW. Screenshots of the graphical user interface and the block diagram for the implementation of the emissions estimation model are shown in figure 3.7.

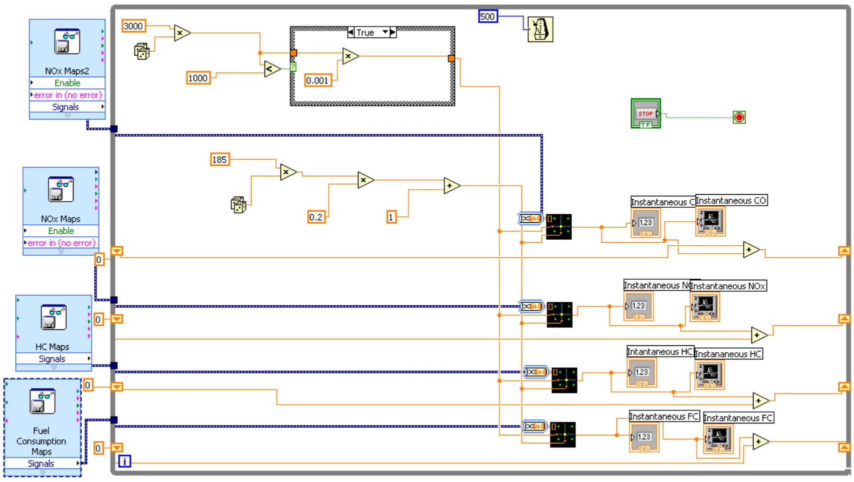


Figure 3.7: Block Diagram Of Emissions Estimation Module

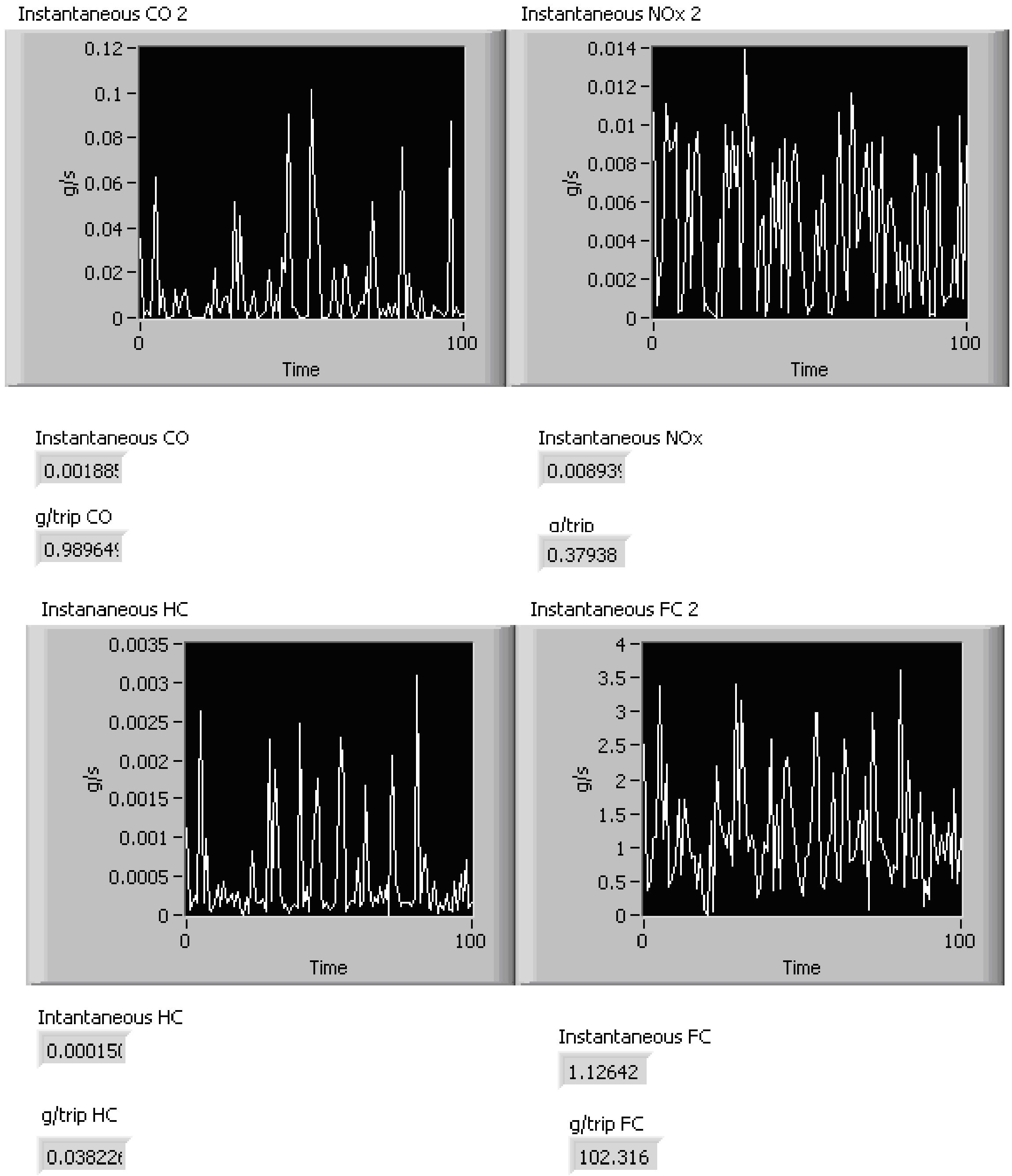


Figure 3.8: Graphical User Interface for Emissions Estimation Module

3.3.3 Cold Start Function Module

Having successfully designed and implemented the instantaneous emissions model, a module was required which indicated the level of cold start excess, emissions and fuel consumption. In order for the model to function correctly, a reference temperature was required. According to the US FTP75 drive cycle, a fully warm engine is assumed when the coolant temperature reaches 23°C. It was as such that 23°C was used as a reference temperature for the proposed cold start function module.

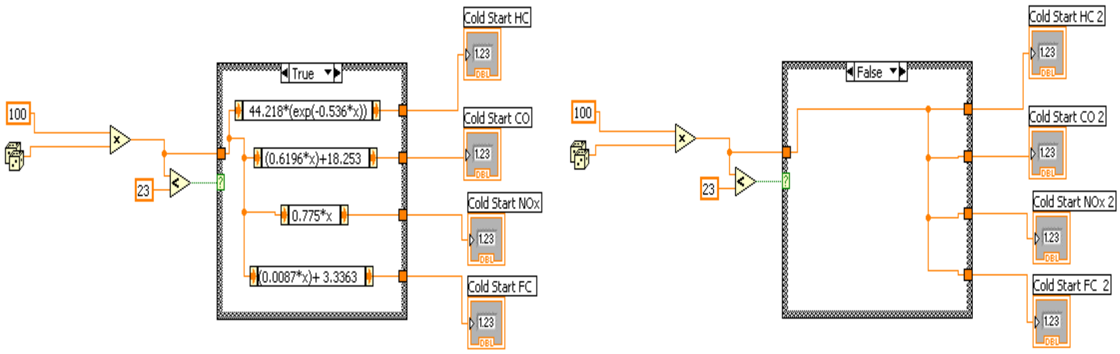


Figure 3.9: Block Diagram of Implementation of cold start excess emissions module

Similarly to the array indexing function for engine speed, the cold start function was implemented inside a case structure. The case structure dictated that if the coolant temperature was above the reference, no action was taken, while if it was below the reference temperature it was scaled according to the cold start factors. The cold start excess emissions were then added to the instantaneous emissions value, giving an overall value for emissions as a function of a particular trip. A screenshot of the block diagram implementation of the cold start function is shown in figure 3.9.

3.3.4 Instantaneous Vehicle Speed and Acceleration Analysis for obtaining a drive cycle.

To obtain a precise drive cycle using the software, a separate module was required, which analyzed vehicle speed and acceleration characteristics. The primary input for this module was vehicle speed. Vehicle speed was read from the OBD in km/hr, this value was divided by 3.6 to give a value of instantaneous speed in m/s. The signal attained for instantaneous speed was then both differentiated and integrated to give values for vehicle acceleration (m/s/s) and distance travelled (m). Functions were also added and analyzed to analyze max vehicle speed, max vehicle acceleration and max vehicle deceleration. Such parameters were required for an accurate overview of driver behaviour. A block diagram of the speed analysis module is shown in figure 3.10.

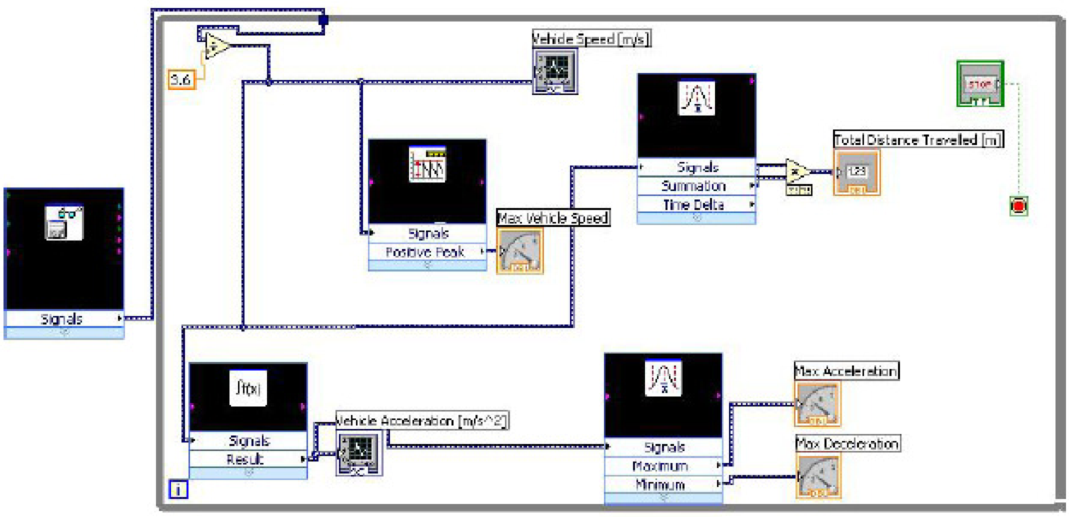


Figure 3.10: Block Diagram For Implementation of Speed Analysis Module

3.3.5 Data parsing module

The data parsing module proved the most difficult module to write. This module was required to intake the hexadecimal values for the various vehicle parameters and output these values in familiar units (e.g. m/s, RPM etc.). In this module the data from the OBD was first scanned for a predefined pattern. (e.g. 41 0C is for an engine speed response). This was achieved using the “match pattern” VI available from LabVIEW. On matching the pattern the VI outputted either the next binary token on the data stream, or the binary token defined by an offset which was set by the programme designer. The outputs from the match pattern VI were then converted to decimal and scaled according to the scaling factors defined by the SAE standards [93].

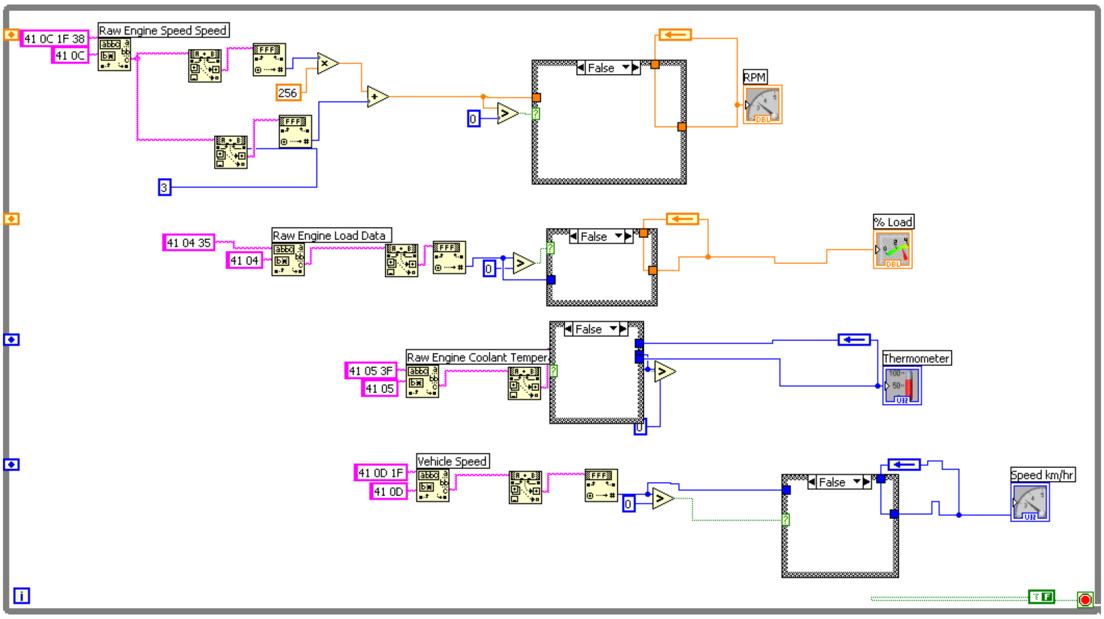


Figure 3.11: Block Diagram Implementation of Data Parsing Module

As the data received was of a serial format, it was required to add case structures to ensure that the values for the various vehicle parameters did not fall to zero during transient periods (periods during which any parsing function was receiving no data). The case structures were designed such that, if a value was greater than zero, it was relayed directly to an indicator. If a value of zero for any given parameter was attained, it was fed through a "for loop" until a value either greater or less than the previously indicated value (but also greater than zero) was attained. Figure 3.11 shows the block diagram implementation of the data parsing module.

3.3.6 Serial Communication Module

Several attempts were made at writing a serial communication module using the VIs available within LabVIEW. Although successful communication was achieved, "framing errors" meant that it was impossible to interpret the data being retrieved.

Communication with the OBD using a HyperTerminal was possible to achieve. Therefore it was decided to use an edited version of HyperTerminal emulation VI developed by a National Instruments technician[a]. The original HyperTerminal emulation was designed to function exactly as the Microsoft Windows HyperTerminal programme, where the user sends commands to the serial port one at a time, and responses are received in the same manner.

In order for the emissions estimation model to function as required, a method of automating the data acquisition process was required. This was achieved by re-writing the HyperTerminal emulation in a "Producer/Consumer" structure. A producer loop places the commands to be sent to the serial port in a queue. This queue is then sent to a timed loop, where the commands were continuously sent to the serial port. A third loop containing an "Event Structure" is used to read response from the serial port. Finally a "Stacked Sequence" is used, so that the port can be initialised and closed before and after data is received on the port. Figure 3.12 shows the block diagram and Graphical User Interface for this module.

Figure 3.12: Graphical User Interface for Serial Communication Module

1- Thanks to Christian Altenbach, Moderator of National Instruments Forum for his kind permission to use his bilinear interpolation VI

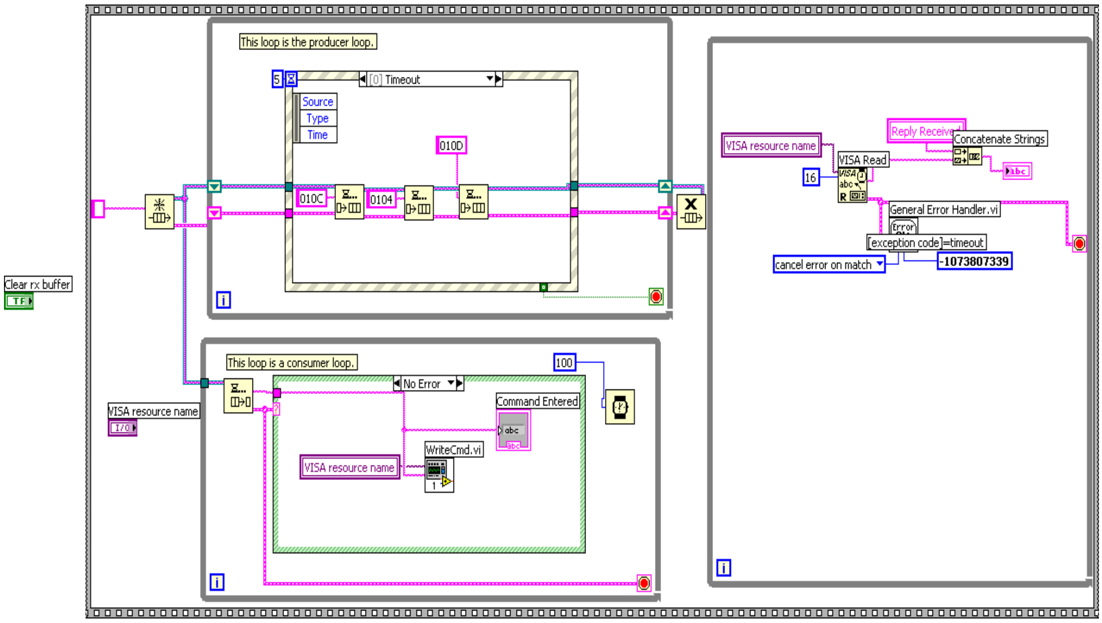


Figure 3.13: Block diagram implementation of serial communication module

3.3.7 Analyzing Logged Data

For both validation and post-processing purposes, a methodology was required of logging data used within and obtained from the programme. The “write to file” VI within LabVIEW offers the user a useful tool in the analysis and post processing of data. This VI enables the user to transfer data from any number of data channels to a comma or tab delimited file (i.e. Excel) stored on the computer memory. LabVIEW also offers the option of placing a time-stamp on each piece of data to aid in the post-analysis of the logged data.

The following data was written to a file for analysis and post-processing:

- Instantaneous Vehicle Speed (m/s)
- Instantaneous Vehicle Acceleration (m/s^2)
- Instantaneous Engine Speed (rpm)
- Instantaneous Coolant Temperature (°C)
- Instantaneous Throttle Position (%)

- Instantaneous Calculated Engine Load (%)
- Instantaneous Load (Nm)
- Instantaneous Emissions (g/s)
- Instantaneous Fuel Consumption (g/s).

3.3.8 LabVIEW Emissions Estimation Program

Having implemented and tested each of the aforementioned modules, all contained interfaces to form a fully functioning emissions estimation programme. Figure 3.14 shows a screen shot of the GUI for the final emissions estimation programme.

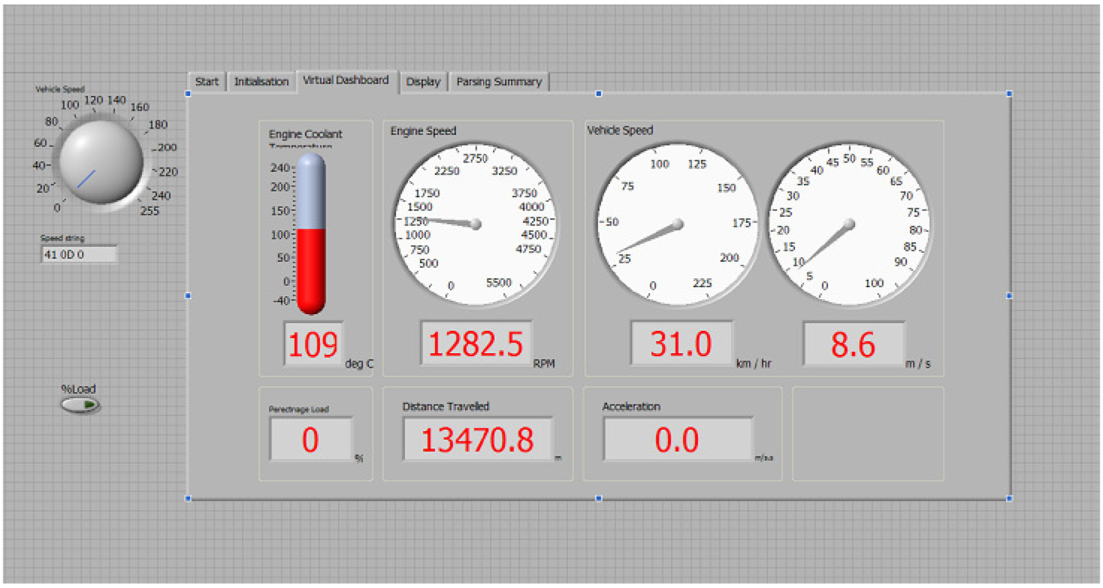


Figure3.14: Graphical User Interface for Final LabVIEW Emissions Estimation Programme

Having completing the tests and logging data into an accessible file, further processing has been applied to draw the driving cycle and emission factors. More details are explained in further discussion.

3.4 Using COPERT

COPERT is a software tool used in many countries to estimate emission factors from road transport. COPERT is under the European Environment Agency (EEA) coordination, in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. The scientific development of the model was managed by The European Commission Joint Research Centre. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. However, it is applicable to all relevant research, scientific and academic applications.

The methodology is part of the EMEP/EEA air pollutant emission inventory guidebook (formerly called the EMEP CORINAIR emission inventory guidebook) for the calculation of air pollutant emissions and is consistent with the 2006 IPCC Guidelines for the calculation of greenhouse gas emissions [96]. The use of a software tool to calculate road transport emissions allows for a transparent, standardized, consistent and comparable data collecting with emissions reporting procedure. The software tool also helps data and emissions reporting procedures to reach accordance with the requirements of international conventions, international protocols and EU legislation.

3.4.1 Why COPERT?

22 countries out of the European member states (EU27) use the model for the official data of road transport inventories to international conventions [97]. As the software developed to estimate the annual national inventory is non-commercial, it can be used by researchers for academic purpose, for segments and small regions [98]. The software also gives a comprehensive understanding of public transport use when compared to private cars [99]. Therefore, a major advantage of this software is that it can be used outside Europe [24, 96, 100 and 101].

3.4.2 COPERT methodology

Emissions can be determined in a number of ways, either by direct measurement of emissions or as seen with COPERT, by the application of emissions factors based on empirical expressions derived from real-world tests [102-103]. COPERT can describe emissions in terms of grams per kilometre travelled [g / km] in function of vehicle speed.

Emission types

There are three general vehicle emission types, one which is minor and two which are major. The minor one is evaporative emissions (E_{EVAP}) which can occur through the vehicle fuel system (storage tank, carburettor/injector system and flow pipes). These emissions occur due to fuel volatility and daily variation in temperature. Evaporative emissions do not occur in diesel engines due to diesel fuel's low vapour pressure (1 mbar at ambient temperature). Figure 3.15, for COPERT methodology, Emissions from evaporation (E_{EVAP}) are only relevant for NMVOC species from gasoline powered vehicles. The other two major emissions are cold-start emission (E_{COLD}) during transient thermal engine operation and hot emissions (E_{HOT}) during stabilised hot engine operation.

$$E_{TOTAL} = E_{HOT} + E_{COLD} + E_{EVAP} \qquad (3.3)$$

The cold emissions are during transient thermal engine operation (cold start) and the formula is:

$$E_{COLD; i, j} = b_{i, j} \times N_j \times M_j \times e_{HOT; i, j} \times (e_{COLD} / e_{HOT}|_{i,j} - 1) \quad (3.4)$$

where,

$E_{COLD; i, j}$: cold start emissions of the pollutant $_i$ (for the reference year), caused by vehicle class $_j$.

$b_{i, j}$: fraction of mileage driven with cold engines or catalyst operated below the light-off temperature.

N_j : number of vehicles [veh.] of class $_j$ in circulation in vehicle class $_j$,

M_j : total mileage per vehicle [km/veh.] in vehicle class $_j$,

$e_{COLD} / e_{HOT}|_{i,j}$: cold over hot ratio of pollutant $_i$ emissions, relevant to vehicles of class $_j$.

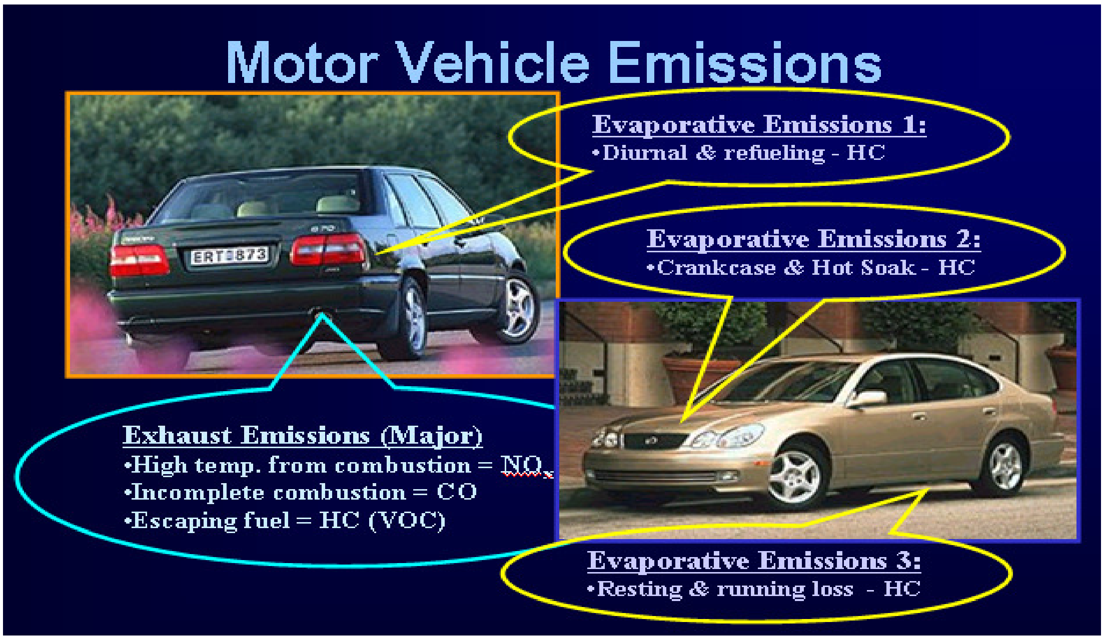


Figure 3.15: emission type illustration.

For the hot emissions during stabilised (hot) engine operation, the formula is:

$$E_{HOT;\ i,\ j,\ k} = N_j \times M_{j,k} \times e_{HOT;\ i,\ j,\ k} \quad (3.5)$$

where,

$E_{HOT;\ i,\ j,\ k}$: emissions of the pollutant i in [g], produced in the reference year by vehicles of class j driven on roads of type k with thermally stabilised engine and exhaust after-treatment system.

N_j: number of vehicles [veh] of class j in circulation at the reference year

$M_{j,k}$: mileage per vehicle [km/veh] driven on roads of type $_k$ by vehicles of class $_j$

$e_{HOT;\ i,\ j,\ k}$: average fleet representative baseline emission factor in [g/km] for the pollutant $_i$, relevant for the vehicle class $_j$, operated on roads of type k, with thermally stabilised engine and exhaust after-treatment system and, $_i$ (pollutants), $_j$ (vehicle class), $_k$ (road class) for 'urban', 'rural', and 'highway' driving and the evaporation emissions from fuel evaporation. Emissions from evaporation are only relevant for NMVOC species from gasoline powered vehicles.

The following formula has been used in this research in order to investigate the correlation of the estimated emission with the real-world ones:

$$EF_{i,\ m,\ n} = \left(\frac{\alpha + \gamma\chi + \varepsilon\chi^2 + \zeta\chi^{-1}}{1 + \beta\chi + \delta\chi^2} \right) \cdot (1 - RF) \qquad (3.6)$$

where, $EF_{i,\ m,\ n}$ is the emissions value, in grams per kilometre travelled [g/km] for a given species $_i$, of age $_m$ and engine size $_n$; *x* is the average vehicle speed in kilometres per hour; *α, β, γ, δ, ε, ζ* are related to the legislative emission factors for that car (i.e. Euro1, 2, 3, etc.); *RF* are coefficients specific to a given engine size $_n$, and technology level.

COPERT coefficients have been used for each car individually in order to calculate the emission factors separately and draw the relationship between them over time. More details have been explained in later paragraphs.

Emissions under different driving conditions

There are three types of emissions in terms of driven routes, as driving conditions in a motorway will differ from those in either rural or urban routes.

$$E_{TOTAL} = E_{URBAN} + E_{RURAL} + E_{HIGHWAY} \quad (3.7)$$

where,

E_{URBAN}, E_{RURAL}, $E_{HIGHWAY}$: total emissions (g) of any pollutant for the respective driving situation.

All these three routes have been taken into account for the investigation of driving cycles. More details are shown in appendix B.

3.5 Gas Analyzer (Second stage)

Two devices of Autologic gas analyzers have been used. The first one runs into a portable PC (laptop) and does not read the emission factors in gram per mile while the second one runs into pocket PC with a built-in software package that can convert emission factors into gram per mile.

3.5.1 Gas analyzer 1

The AutoGas Emissions Analyzer is a portable gas analyzer with PC software which can be run on any Windows PC. It is designed to be used in an environment where both high durability and excellent accuracy are critical to diagnosing vehicle problems. The analyzer hooks up to a laptop via a USB port which with the software installed on the computer displays the emissions info on the laptop screen. The analyzer can measure 5 separate types of gas HC, CO, CO2, O2, NOx and also Lambda and Air Fuel ratio. The analyzer has excellent performance requirements for measurement specifications such as ASM/BAR 97, OIML, and BAR90. The analyzer is mounted in a case that keeps all connections safe from accidental dropping [4]. The software included makes this a complete stand-alone unit when connected to any PC running Windows 95, Windows 98, Windows NT, Windows ME, Windows 2000 and Windows XP with one available com port and one available USB port.

3.5.2 Setup

System connections Figure 3.16

A. Water / exhaust outlet
B. Vacuum seal quick disconnect
C. Sample probe connector
D. Zero air port
E. Calibration port
F. PC RS232 (serial) connector
G. 12V power input connector
H. PC power connector

Figure 3.16: Autologic gas analyzer [4]

The following steps were carried out in order to use the device:

1) Place the thread emission sample probe into the emission sample hose, figure 3.17.

Figure 3.17: Emission sample probe [4]

2) Connect the emission sample hose to its mating spring lock coupling on the gas analyzer as seen in Figure 3.18.

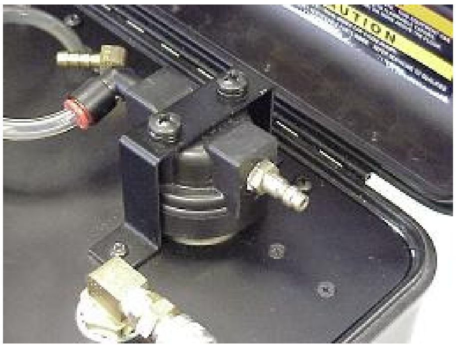


Figure 3.18: Emission sample hose mating spring lock coupling [4]

3) Connect the water/exhaust hose, figure 3.19, to its mating spring lock coupling on the gas analyzer. When the gas analyzer is located in a vehicle for testing, make sure the open exhaust hose end is routed outside of the vehicle window and does not obstruct the operations of the driver.

Figure 3.19: Water/exhaust hose [4]

4) Connect the PC serial cable as appropriate for the configuration being used, figure 3.20.

Figure 3.20: PC serial cable [4]

5) Thread one of the analyzer power cables into the gas analyzer and connect the other end to the end of the power supply cord. The cigarette lighter cable threads directly into the gas bench, figure 3.21.

Figure 3.21: DC power adaptors [4]

6) At this point, everything is connected and ready. Power on the PC, go to the start menu select programs, locate and select the Auto gas emissions analyzer menu item and run the software [3].

The gas analyzer is capable of measuring HC, CO, CO2, Lambda, Air Fuel, and NOx. The analyzer can also measure the RPM and oil temperature of the travelling vehicle.

As the analyzer runs, there is a build up of excess water. To reduce excess water production, an automatic water removal mechanism is incorporated into the analyzer to remove water from the vehicle exhaust as the analyzer runs. The water is removed continuously as the system is operated to eliminate frequent purging [4]. A unique float system is integrated into the setup that prevents damage to analyzer if the exhaust sample probe lands in water.

To help guarantee accurate emissions readings, a zero air port allows the gas analyzer to be reset to zero for calibration without removing the sample probe from the vehicles exhaust pipe. The accuracy of this system meets and exceeds the accuracy specifications of ASM/BAR 97, OIML and BAR90 standards.
With a universal power supply for 90-230 VAC, a 50-60 Hz 12 Volt Cigarette lighter plug and 12 volts battery clamps included, the Analyzer can be either used in house or for on road emission determination. Used with either a laptop or desktop based PC, the gas analyzer is user friendly for either indoor use or on the road.

3.5.3 **Software Features**

The following are the characters of the software interface:

- Large digital meters Figures 3.22 and 3.23 with pull-down lists for easy viewing of gases from any distance.
- One touch clicks for data recording. Record data over long profiles using 1 second intervals or change intervals for tests like engine braking.
- International software with English and Metric units. Built in language translation allows software to be translated without programming knowledge.
- Data saved in industry standard database format. Great for research and development facilities who wish to record emissions data. Often a technician may start work on one vehicle and move to the next vehicle before finishing

the first. The database stores a large memory storage capacity allows users to work on numerous vehicles simultaneously without deleting data.

- All emissions are tied to the customer and vehicle facilitating recalls for comparison purposes.

Figure 3.22: Digital gas analyzer meters [4]

- Two speed idle (TSI) test in addition to digital readout of emissions: This enables easy comparison to state inspection test results. This also provides garage owners and technicians with an easy way to assure that everyone is testing the vehicle the same way before and after repairs. Data is collected automatically and the technician is guided through the test with clear on screen prompts.
- Real time graphing of emission data allows viewing of trends and quick comparison of signals, figure 2.24.
- Software runs on any PC running Windows 95, Windows 98, Windows NT, and Windows ME, Windows 2000 and Windows XP with one available com port and one available parallel port. Optional kit available for users with only USB ports.

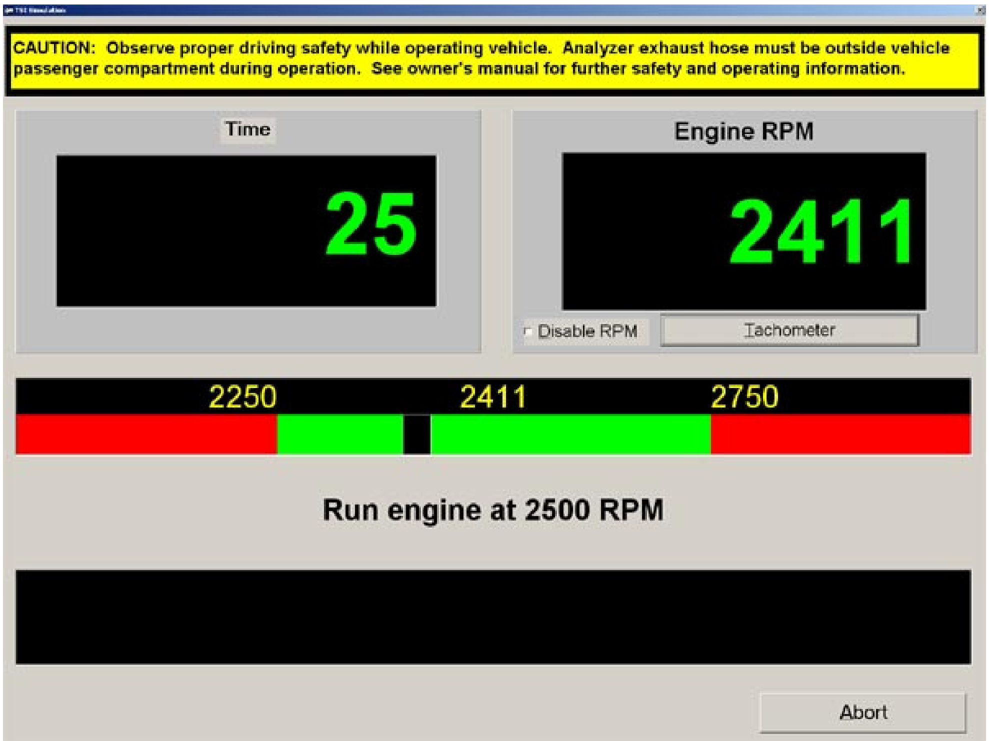


Figure 3.23: Digital engine speed meters [4]

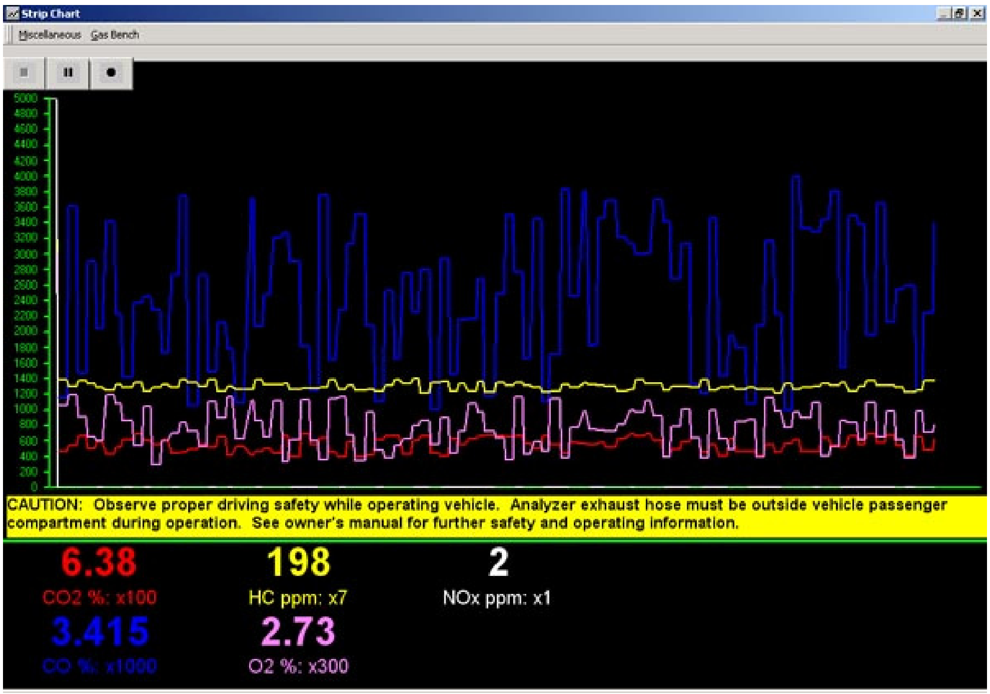


Figure 3.24: Gas Emissions graphs [4]

Table 3.4 Gas Measurement Ranges

	Range	Resolution
HC	0-2000 ppm	1 ppm
CO	0-15%	0.001 vol%
CO2	0-20%	0.01 vol%
O2	0-25%	0.01 vol%
NOx	0-5000 ppm	1 ppm

Table 3.5: Environment measurement ranges

Temperature: 0 - 50 °C oper, -20°C to 70°C storage
Humidity: Up to 95% non-condensing
Altitude -300 to 2,500 m
Vibration 1.5 G sinusoidal 5-1000 Hz.
Shock 1.22m drop to concrete floor (gas analyzer)
Response time 0-90% <= 8 seconds for NDIR measurements

3.5.4 Gas analyzer 2

The major difference between the two devices is that the second one can show the emission factors in gram per mile then with quick conversion to gram per kilometre was obtained.

3.5.5 Pocket Gas PC

Pocket Gas is software designed for conducting diagnostics using a gas analyzer to perform several types of tests and recordings. It provides the possibility to record these tests and print the results for future reference.

The devise used is the IPAQ from Hewlett-Packard. Data from the analyzer can be transferred to its software via either weird cable or Bluetooth, figure 3.25, which is better for ease of use.

Figure 3.25: Pocket PC and Bluetooth adaptor

General configuration

The following guidelines outline the configuration parameters on the general tap:

- Bench type is used to select the gas bench being used.
- Comm port is the port in the pocket PC that will be used to communicate with the gas analyzer (in our case it was 8).
- Bluetooth is used instead of the communication/serial cable.
- Rate (sec) is used for the rate at which the meters are updated on the main pocket PC window.

Those parameters should lead to the final display while doing the test as seen in Figure 3.26.

3.5.6 Data Converting

Having logged and saved results in the pocket PC, data transfer to a computer was required to process the results and perform the analysis targeted. Firstly, software was needed to be installed in the computer in order to be able to synchronise with the pocket PC. Secondly, few zipped files were requested from Autologic in order to obtain the emission factors in gram per mile as this unit [gr/km] was upon request). Finally, a *.txt file with all data recorded was obtained each time pocket pc was synchronised with the computer. It would therefore be able to copy this data into an excel file for further processing in order to draw the relationship between emission factors and time. Further details will be discussed in the results section.

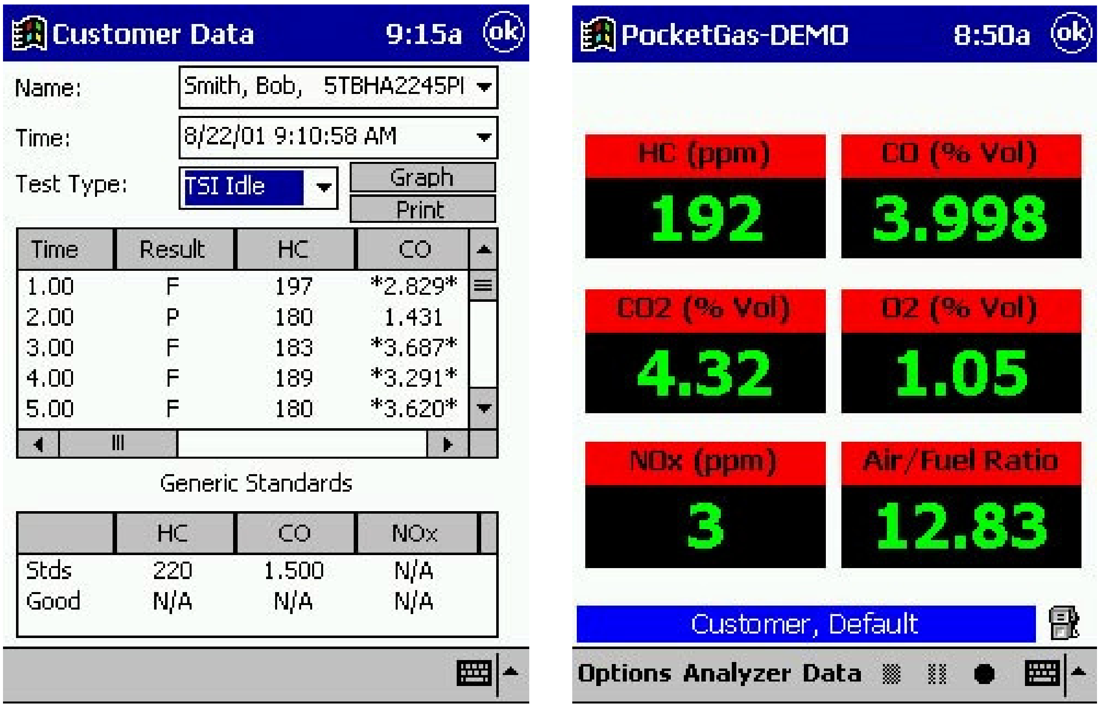


Figure 3.26: Pocket Pc display [4]

3.6 Test trips

Tests were carried out through the use of a specified test cycle which aimed to simulate real world driving patterns. Unfortunately, estimates obtained from such test methods were not wholly representative of real world emissions as real world driver behaviour and driving conditions can be difficult to accurately model. The scope in these tests was divided to three sections:

- Many experiments that have been done since early stage testing were necessary to investigate the method involved in this research. This included stand still tests, around DCU campus trips and finally DCU motorway junction trips. The OBD reader along with labVIEW package was used on different routes and vehicles. These various setups were essential to give a comprehensive usage of the software used.

- Comparison of emissions estimated with the gas analyzer data in the second stage. These results were evaluated in order to determine the accuracy of the software used. Both stages were done in Dublin city.
- The third stage of the research study was carried out in Aleppo city. This stage consisted of a preliminary case study on the estimation of the emission values taken from a passenger car.

3.7 Early stage tests

3.7.1 Standstill tests

Standstill testing allowed recording of gas analyzer background data. This motionless test meant that certain parameters were eliminated in these tests such as speed, traffic jams and driving characteristics. The purpose of the test was to recreate a situation of rush hour traffic where a car is stationary while car engine remains running. This was done in DCU car park, the model of the car was a FORD Focus (registered in 2006) with legislative standard Euro4 as described in Table 3.6

Table 3.6: car specifications (Ford Focus 2006)

Parameters	Value
Weight	1225-1410kg
Engine	1.4L capable of 79bhp
Transmission	5 speed gearbox with reverse gear
Emissions Specifications	CO_2 164g/km HC 0.037 NO_X 0.012

Figure 3.27 shows the gas analyzer setup where the probe was inserted in the exhaust tail pipe and fixed to the car. Power was supplied from car cigarette lighter socket while 12v battery was used in case cigarette lighter is not working.

Figure 3.27: gas analyzer fitted in the car

The revolutions per minute were kept constant for about 10min at around 770 rpm, and then the rpm was increased up to between 1400 rpm and 1600 rpm. The car was kept in neutral as to ensure that a real world practice was obtained.

3.7.2 DCU campus trips

This short urban route testing was not one of the routes initially under consideration. However this testing allowed testing of shorter urban routes which would provide certain assumptions for when testing the motorway. The use of a simple urban route to reliably compare emissions accurately was particularly interesting at later stages of the study. The primary route chosen was just an encirclement of the DCU university campus. This route would take:

- All necessary characteristics of an urban route such as constant acceleration, deceleration and stopping into account.
- Take into account certain driver behaviour as it has long stretches of roads where high speeds can be reached and also many corners and traffic lights which will require the driver to slow down and stop.

- Give an insight on driver behaviour as quick acceleration, late braking, gear selected and speed could be consistently compared. All these factors would influence exhaust emissions and could therefore be taken into account when comparing the estimated results with the actual results.

The overall length of the route was slightly less than 4.5 kilometres. The testing started at 10.30am and was completed by 10.45am. There were a total of 2 stops throughout the testing and a total of 3 corners were reached. After each corner there was powerful acceleration which allowed the car to reach speeds of up 60km/hr. It can be seen from the map, Figure 3.28 that there are 4 corners. Unfortunately only 3 corners were taken as a result of a diversion which was in place at the last corner and required a detour through a local housing estate which was situated close to DCU. Although this test was not carried out on the preferred routes during the specified times which are required it provided information that proved important at a later stage as results were compared.

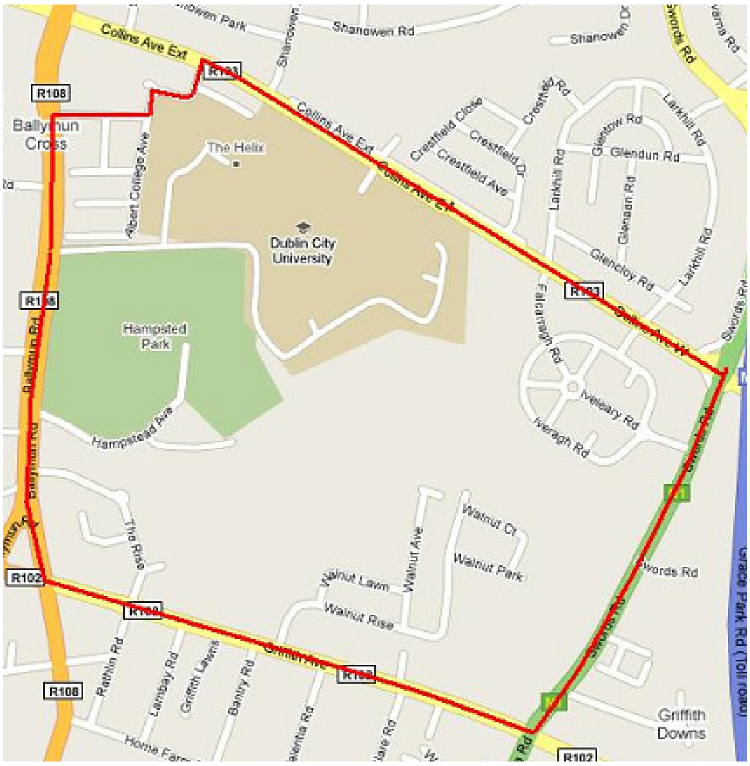


Figure 3.28: Primary DCU route (Google maps was used in all routes trips)

Through testing of the short urban cycle, gears would be changed within every 2,000 to 3,000 rpm. The reason for this is that it will support further studies that variable factors are accounted for. These factors have a significant effect on fuel consumption and therefore emissions. Throughout the testing, a total of 23 gear changes which included 14 up shifts and 9 downshifts were achieved. This type on driving behaviour would have an effect on fuel consumption and therefore has an effect on emissions and was taken into account in the analysis.

3.7.3 DCU Motorway trips

The driving cycle was developed through the use of micro-trips. A micro-trip is a journey between two routes to a single destination. Data from the real world is recorded with the use of a micro-trip. This type of analyzes tracks a vehicle along its route (mainly motorway dividing up into several micro-trips). In most cases, the observed data closely matched the cycle that has just been analyzed. This is primarily done by grouping the representative trips together. In this study, a comparison of different road types was needed using test routes such as one with a motorway and a second road or urban route. By comparing these road types, speed-time profiles could be used because of the changes in road types. Therefore, overall vehicle driving conditions could be collected by roadway type allowing cycles to be constructed to represent driving activity for specific roadway types and traffic conditions.

In the case studied, the micro-trip consisted of a journey between DCU and an area of interest in Finglas, Figure 3.29. These trips took into account all driving patterns associated with most cities throughout the world. These characteristics included constant driving speed, acceleration, deceleration and continuous stopping.

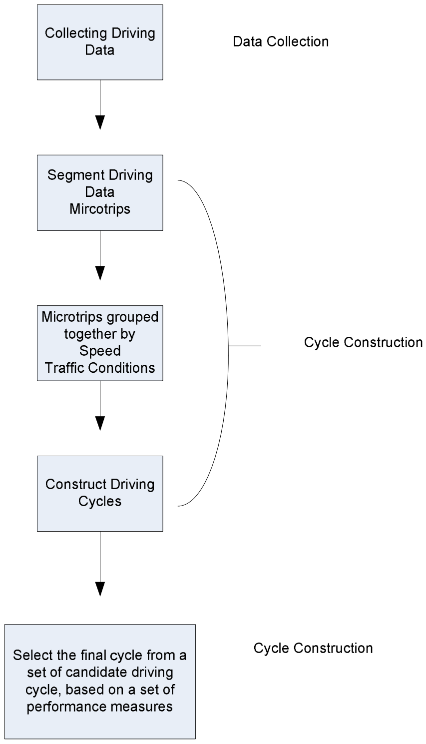


Figure 3.29: Considerations of Micro-trips Construction

The test was carried out via Ballymun road, the M50, Finglas and Glasnevin Avenue taking all road classification into account, Figure 3.30. The length of each section of the test route was almost 7km (7km of motorway and 7km of urban route). In this test, the emissions of CO, NO_X, HC and fuel consumption were determined.
It is important to remember that when conducting these tests certain aspects such as weight, engine size and fuel emissions need to be taken into account. For the test, a number of parameters had to be held constant to ensure that a comprehensive overview can be undertaken. This comprehensive overview would be useful for further research on a similar vehicle to the test vehicle if needed.

Throughout the test it was recorded that the total number of gear changes where 51 times. These changes consisted of 28 gear changes for a higher gear and 23 gear changes for slowing down. The route also consisted of 10 complete stops for red lights and the corresponding roundabouts situated throughout the route. In this test it is important to mention that not all gear changes where done between the

2,000 to 3,000 RPM. There were 7 instances where the 3,000 RPM limit was exceeded. This in turn will have an effect on fuel consumption as the number of revolutions per minute is proportional to fuel consumption and emissions released. This should be taken into account with the OBD and related software as to ensure maximum accuracy when estimating the emissions of the entire route.

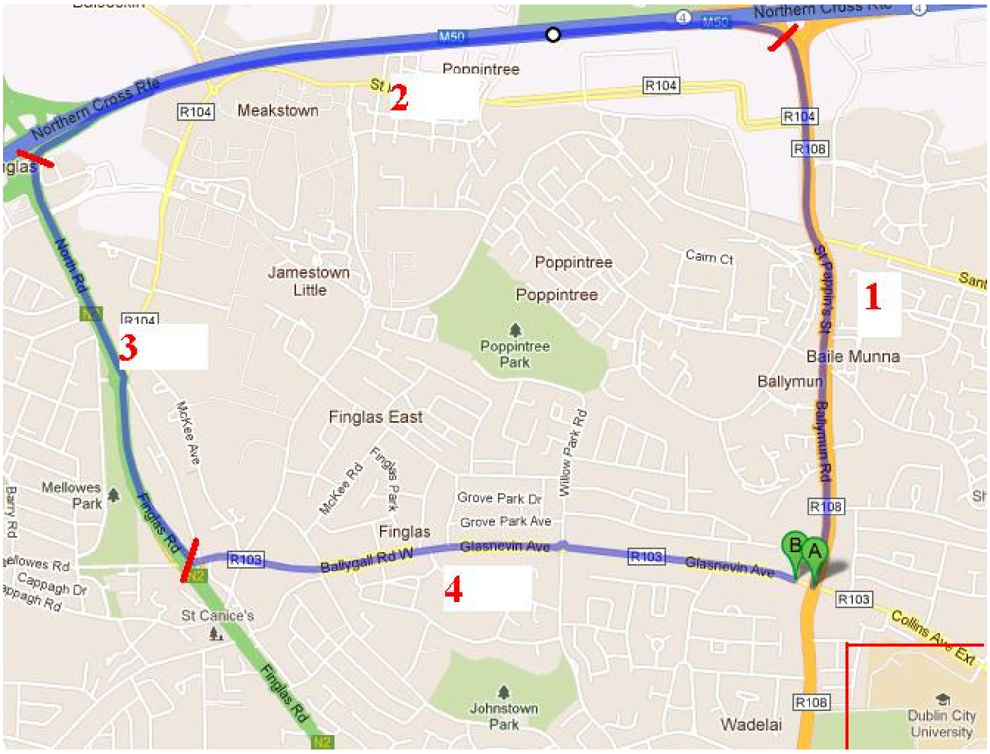


Figure 3.30: DCU-Motorway map

3.8 Evaluation of the emission estimated (second stage)

3.8.1 DCU-Dundrum trips

Figure 3.31 describes the methodology used in the experiments. this flow chart will simplify the method involved for developing the driving cycle, OBD tool and gas analyzer were used in parallel during the experiment, OBD connector was transmitting the data from the OBD system into the laptop using the program interface and saving these data into a file that can be accessed by Microsoft office Excel. While at the same time the pocket pc was storing the data from the gas analyzer. When the trip is finished, data from both methods are taken then data obtained from OBD was analyzed and refined then driving cycle was plotted, then from the driving cycle, estimated emission factors were obtained, then compared with measured emission factors were obtained from gas analyzer.

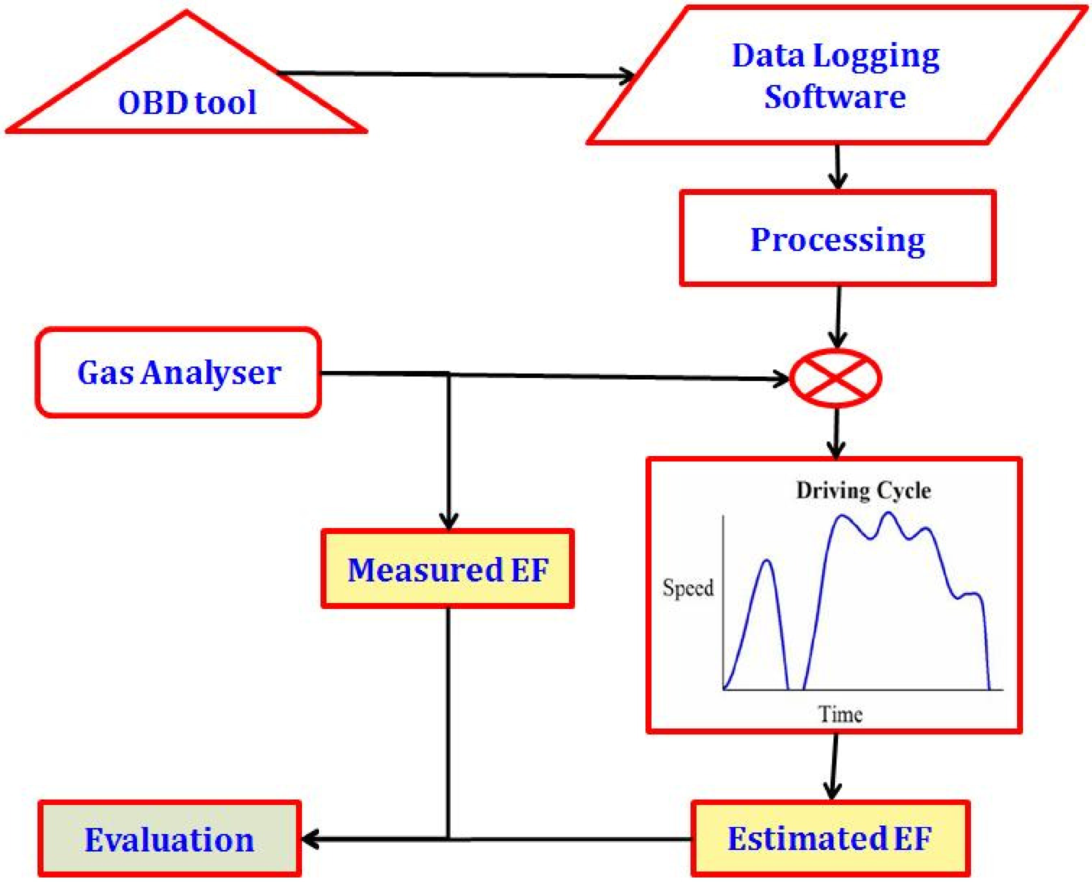


Figure 3.31: Flow chart of development of Driving Cycle

The spark ignition vehicle tested was passenger car; model Ford Focus, year 2001, engine capacity 1600cc, and legislative standard Euro 3. Two trips have been done through these early stage tests. The first test was via the city centre during rush hour from Ballymun Road exit of the DCU university campus to Dundrum. The second test was via the motorway for the same destinations as specified in Figure 3.32 and Figure 3.33.

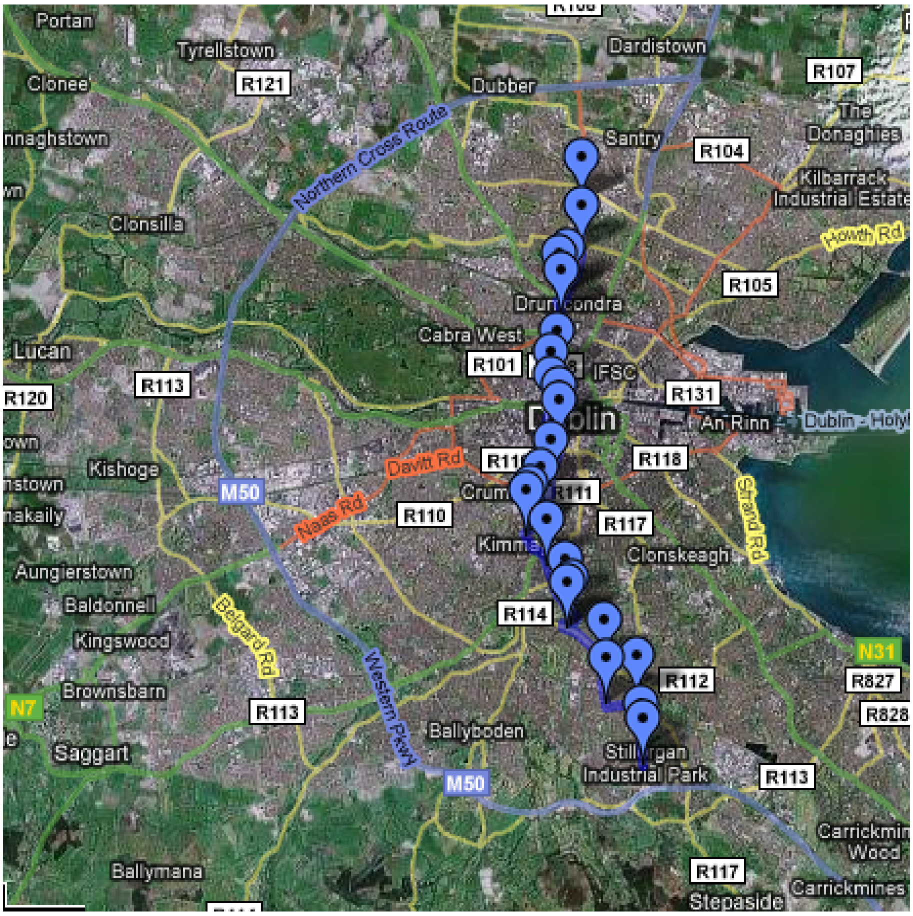


Figure 3.32: DCU Glasnevin to Dundrum via City centre

Two participants were on-board. The first participant was driver who has been trained to drive naturally as if there were no measurement devices on his car and the second participant was the technician who monitored the two devices while working to ensure normal results have been taken.

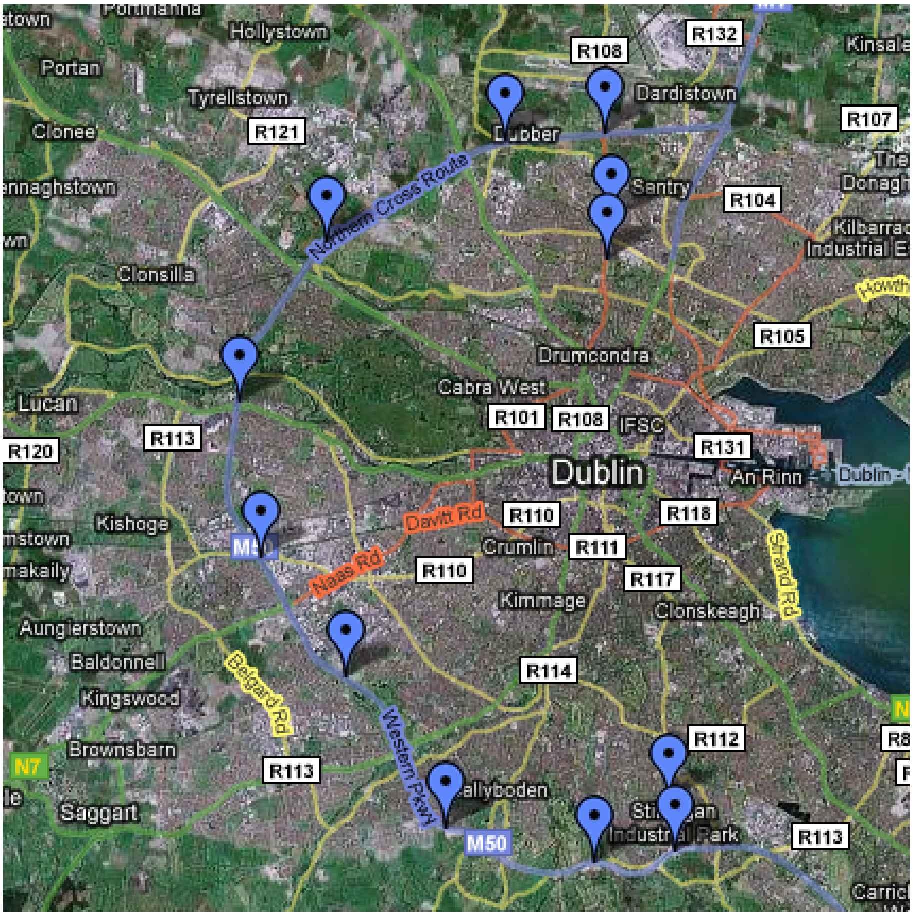


Figure 3.33: DCU to Ballymun exit of M50 to Dundrum via M50 motorway

3.8.2 DCU-Dublin city centre trips

For these series of tests, cars used were limited due to the availability of cars that are compatible with the OBD scan tool such as the NISSAN Micra, FORD Focus, FIAT Marea, TOYTA Camry, HYUNDAI Verna.

The test was carried out on a passenger car with the following specifications: the model of the car is Fiat Marea, year 2001 with an engine capacity of 1.6 L and the legislative standard is Euro3. Table 3.7

Table 3.7: Engine specifications of the car tested.

Fuel type	Gasoline	Fuel system	Normal
Bore x stroke	80.50 × 78.40 mm	**Catalytic Converter**	Y
Bore / stroke ratio	1.02	**Max. output**	76kW @ 5750 rpm
Displacement	1596 cc	**Max torque**	145Nm @ 4000rpm
Compression	10.5	**Coolant**	Water

The tests were performed on three different periods of time by focusing on the most important rush hours times. The first test was performed between 8.00 and 10.00, which covers a typical commuter time period. The second test was run between 16.00 and 18.00, which all covers a typical commuter time period. Finally, for comparative purposes, the last test runs were performed between 21.00 and 22.00 where traffic would be significantly less.

These tests were taken place on two main routes covering two major roads, which link Dublin City University (DCU) with Dublin City Centre. Route I, starts from DCU university main gate at Collins Avenue towards upper Dorset street through Botanic road with a total distance of 5 km as shown in Figure Whereas, route II starts from upper Dorset street towards DCU main gate at Collins Avenue through Drumcondra road with a total distance of 4 km as shown in Figure 3.34. In total, eighteen test runs were performed on three non-consecutive days. In order to measure the emissions, the Autologic gas analyzer model was used which operates directly via the exhaust pipe.

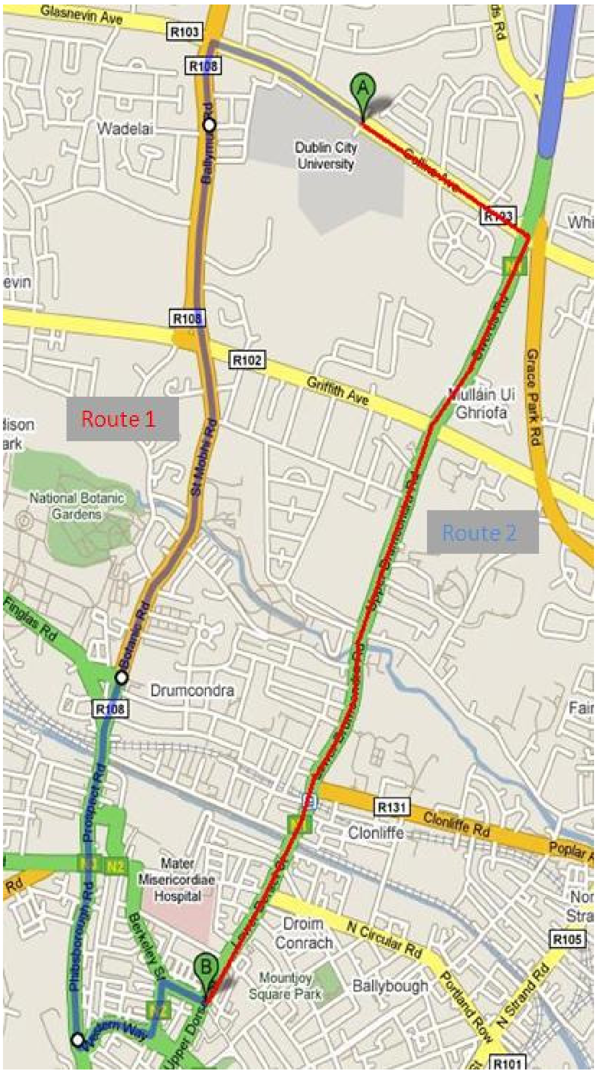


Figure 3.34: Routes that were employed during the tests.

3.9 Implantation the methodology in Aleppo, SYRIA (third stage)

Syria is classified as a lower middle-income developing country with an average annual growth rate of 2.2% of per capita GDP since 2000; and a population growth rate of 2.45% in 2006 and 2007. The country formally adopted the environmental impact assessment system in 2008 and a comparative research with other systems shows a significant step forward since 2008 [104].

Aleppo is the second capital city located in the northern border with Turkey with an area of 16,000 km² and has a population of 4,393,000 making it the largest Governorate in Syria by population. The main source of this city is the agricultural products of the surrounding region, mainly wheat, cotton, pistachios, olives and sheep. Also it has been known as a trade and an industrial city. As an educational part, the University of Aleppo was established in 1958 with twenty five academic faculties, 10 intermediate colleges and 126,861 students in 2008.

Figure 3.35: Traffic in city centre.

Figure 3.36: City centre measuring station

Traffic is one of the biggest problems in Aleppo, Figure 3.35. There is not any major solution found for this big problem yet. The city has only few measuring stations for air quality. However, detailed surveys of the traffic (counts, origin destination) were still carried out in the city centre as well as the Old City where the air pollution is critical and human population density is high. Figure 3.36 shows the location of the station for city centre at President Square and Figures 3.37 and 3.38 show the daily report of CO and NOx emissions which mainly come out from vehicles. Evaluation of the impact of the planned package for a cleaner transportation system around and inside the Old City would be useful.

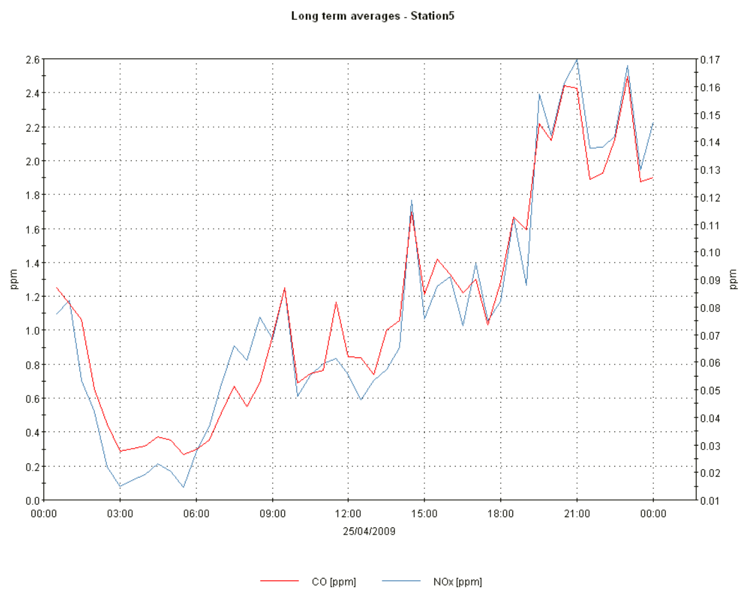


Figure 3.37: Daily monitoring of CO, Nox in a weekend day

In Aleppo city, there are more than three hundred fifty thousand light duty vehicles running almost daily and there is no sufficient document providing accurate figures engine capacites used. Table 3.8 shows the total number of cars in Aleppo and how cars are divided into six sections and not three sections as seen internationally, (i.e. K≤1.4L). Also it was noticed from the table that almost 50% of cars are with unknown engine capacity and there are no alternative fuel system cars taken into account in the data given while some of the countries are carrying out a comparative study of vehicles using bio-fuel and compressed natural gas (CNG) [80].

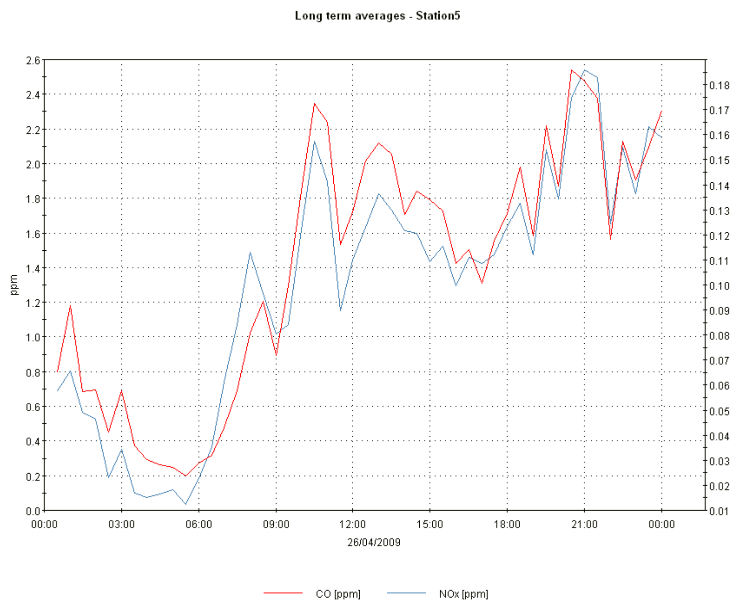


Figure 3.38: Daily monitoring of CO, Nox in a workday.

Table 3.8: Total number of cars in Aleppo city.

Engine capacity K (litre)	Petrol cars	Diesel cars
1≤ K	38986	1358
1<K≤2	106952	340
2<K≤3	6107	12032
3<K≤4	2323	2880
4<K≤5	376	880
5<K	257	6592
Unknown K	97072	79527
Total	252073	103609
Grand total	355682	

In China, much research has been done on energy consumption analysis and fuel types were compared with each other including alternative fuel systems which are leading to more development in fuel technology [105]. This development can in turn reduce the oil consumption for transport [79]. In parallel with these developments; the transport sector has a good effect on a viable eco-driving strategy and reduction of excess fuel consumption [82]. In fact, many of these researches have to be applied in the developing countries as the transport sector is facing problems in oil supply. Also there will be increased use of renewable energy in the near future [81]. An example of alternative fuel development includes the use of a proton-exchange membrane fuel-cell for transport in United Arab Emirates [106]. To simplify the method involved in Aleppo experiment, OBD connector was transmitting the data from the OBD system into the laptop using the program interface and saving these data into a file that can be accessed by Microsoft office Excel. Data was analyzed and refined then driving cycle was plotted, then from the driving cycle, estimated emission factors were obtained. Figure 3.39 described the development of Driving Cycle in Aleppo city.

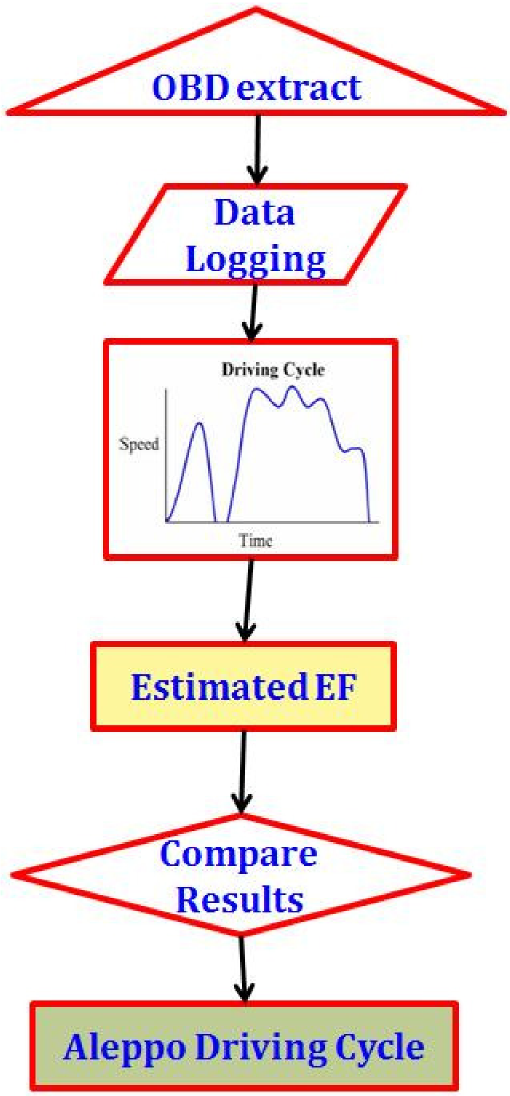


Figure 3.39: Flow chart of development of Driving Cycle in Aleppo city

3.9.1 Home to work scheme

As it is the first time such a driving cycle for the city of Aleppo has been done, many trips have been implemented in order to optimize the results obtained from those trips. The first spark ignition vehicle tested was a KIA Rio (registered in 2007) with legislative standard Euro4 as described in Table 3.9.

Table 3.9: Engine specifications of KIA Rio.

Fuel type	**Gasoline**	**Displacement**	1599 cc
Bore x stroke	76.45×87.12 mm	**Max. output**	110Kw@6000 RPM
Compression ratio	10.0:1	**Max torque**	107Nm@4500 RPM

Three trips have been carried out on a daily basis. The first and second trips were during peak hours (going to work and back home) and the third was in the evening time for the same route Figure 3.40. The total trip distance was nearly 6km.

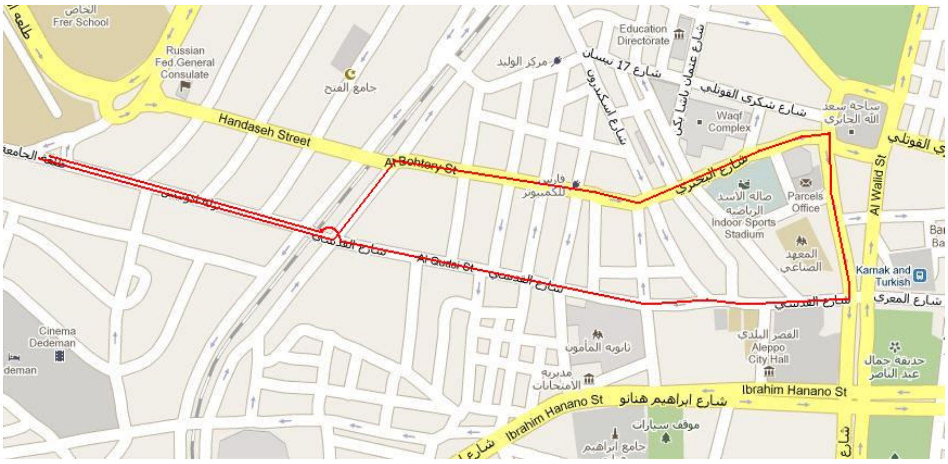


Figure 3.40: The route used by the first car. (Home-Work phases)

3.9.2 Aleppo university campus

The second phase was to assess the emission factors produced from tests carried out on another car in order to implement the methodology used in this research. The second spark ignition vehicle tested was a passenger car. The model was a TOYOTA Camry (registered in 2009) with a legislative standard Euro5, Table 3.10.

Two trips have been done. The first was during peak hours around Aleppo University Campus. The second was in the evening time for the same route. The total trip distance was nearly 6km as displayed in Figure 3.41.

Table 3.10: Engine specifications of TOYOTA Camry.

Fuel type	**Gasoline**	**Displacement**	2362cc
Bore x stroke	88.5×96.00 mm	**Max. output**	118kW@6000 RPM
Compression ratio	9.8:1	**Max torque**	218Nm@4500 RPM

Figure 3.41: Aleppo University campus

Chapter 4 Results & Discussion

All engine parameters have an effect on fuel consumption and exhaust emissions. Pedal operations can form the basis of typical driving patterns. The changes in position of the pedals, engine speed and vehicle can all have a significant effect on how a driving cycle can be misunderstood. Parameters such as road speed, gear and the pedal positions of the accelerator, brake and clutch collectively describe the choices made by the driver. These choices consequently have an effect which may be used to define the driving cycle. Table 4.1 displays the different vehicle parameter effects on emissions and fuel use.

Table 4.1: Driving pattern factors effect on emissions and fuel consumption

Driving Pattern	Fuel	CO	HC	NO_X
Deceleration	No Effect	No Effect	No Effect	No Effect
Quick Acceleration	Significant	Significant	Moderate	Significant
Stop Factor	Extreme	Extreme	No Effect	No Effect
Speed Fluctuation Factor	Minor	Minor	No Effect	No Effect
Moderate Acceleration	Minor	Minor	No Effect	No Effect
Extreme Acceleration	Minor	Minor	Extreme	Extreme
Late Gear Change 2-3	Insignificant	Insignificant	Minor	Moderate
Engine Speed ≥ 3,500rpm	No Effect	No Effect	Minor	Minor
Factor for Low Engine Speed	No Effect	No Effect	No Effect	No Effect

In this chapter, each stage and its corresponding case were studied individually. The outcomes of these studies showed a comprehensive conclusion to case study.

4.1 Early stage results

4.1.1 Standstill tests

Engine was running for 10 minutes at constant engine speed. During this operation, slight increases in emissions were noticed. Small peaks of emission factors at variable times occurred due to factors such as clean fuel, catalyser performance, engine maintenance, cooling system, etc. After this time period, the driver was asked to press the accelerator pedal in order that the engine speed was between 1400-1600rpm. From the same figures, it was noticed that when there was an increase in engine speed, a corresponding increase in the amount of emissions produced was noticed.

In the case of Hydrocarbon emissions, there was an increase over the 10 minute test period. This concluded that as time increased the HC emissions increased gradually. The level of HC emissions also increased with increased engine speed. The amount of HC emissions respond to subtle changes in lambda (the angle of throttle) which is in stark constant to the amount of CO emissions from the same change of lambda. The Carbon Monoxide production differs when lambda changes.

When the number of revolutions increased there is a sharp increase in the amount of CO produced but then drops back to a level that is higher than the previous levels. This means that over an extended period of time as the engine speed is kept constant at a higher level, the sum of CO is increasing constantly. In general at low engine speed, the amount of CO being produced is higher that the corresponding HC emission values as it shown in figure 4.1.

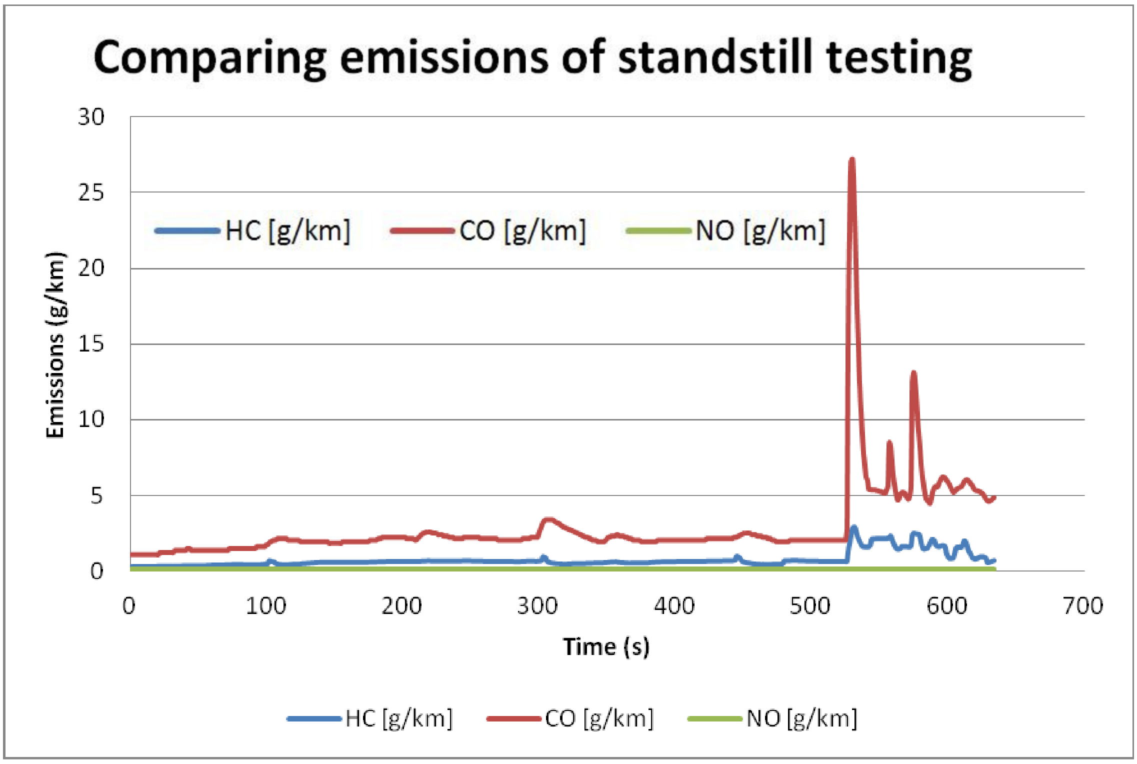


Figure 4.1: Comparative of Emissions during Standstill Testing

Figures 4.2 and 4.3 show the breakdown of the emissions of HC and CO. These graphs show in depth how the exhaust emissions are effected when the engine speed is increased during a standstill test. Each graph shows the time between the revolutions being kept at a constant value and being increased and how this increase affects each of the pollutants HC, CO and NOx. In comparing HC and CO to each other, the amount of CO produced during standstill was on average 2.92g/km whereas the amount of HC produced was only 0.73g/km. This can be seen when comparing the two graphs during the time where the engine was kept at 770rpm. The amount of HC produced was only 0.96g/km compared to 3.406g/km of CO produced. Another difference is that the peaks of HC are sharp and higher than the peaks of CO and this again due to the parameters mentioned previously.

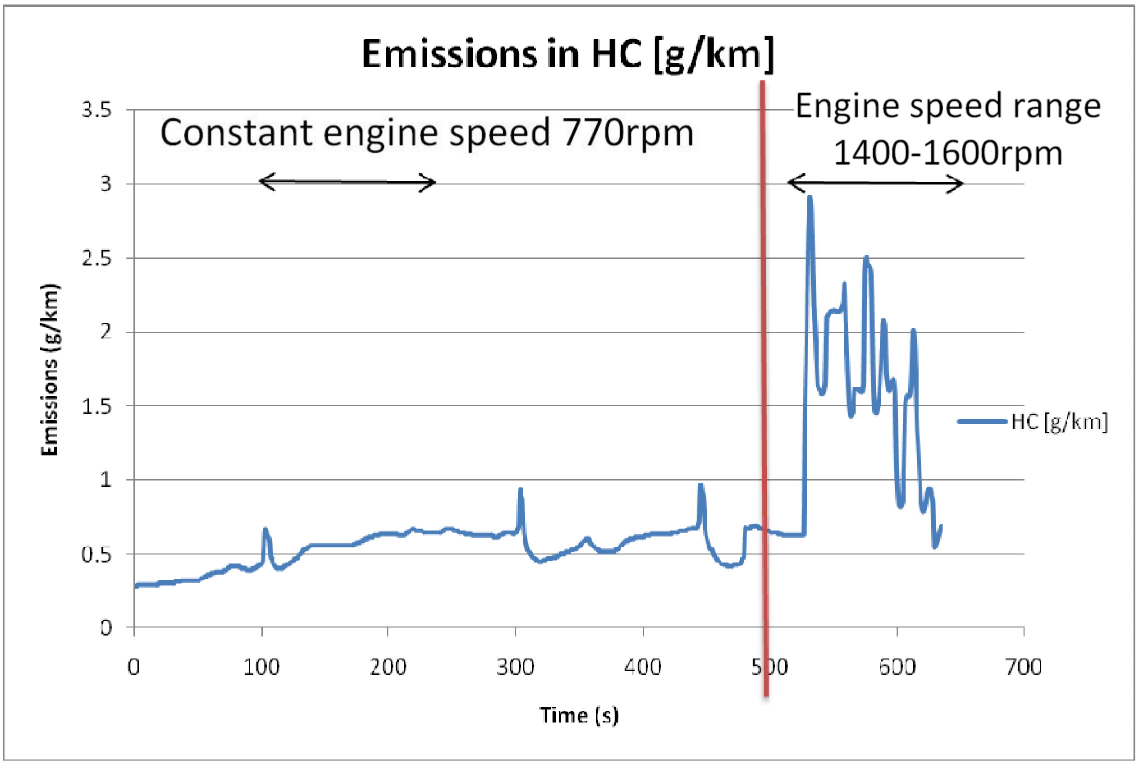


Figure 4.2: Hydrocarbons Emissions of Standstill Testing

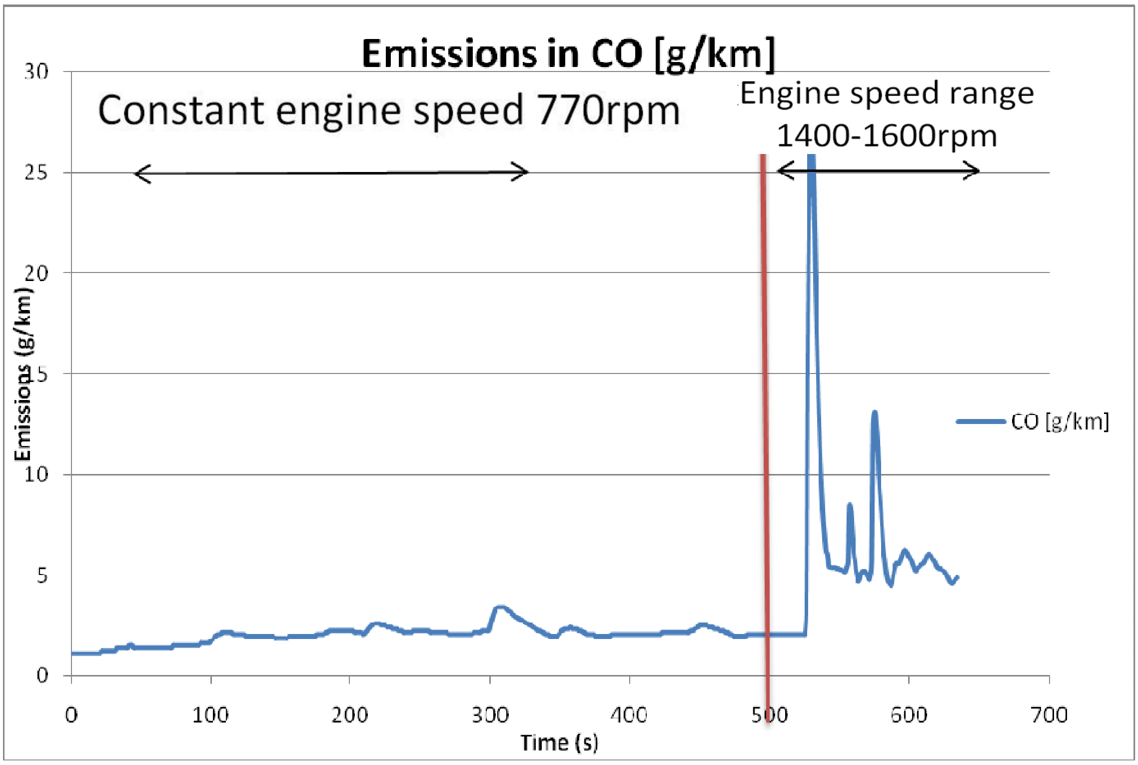


Figure 4.3: Carbon Monoxide Emissions of Standstill Testing

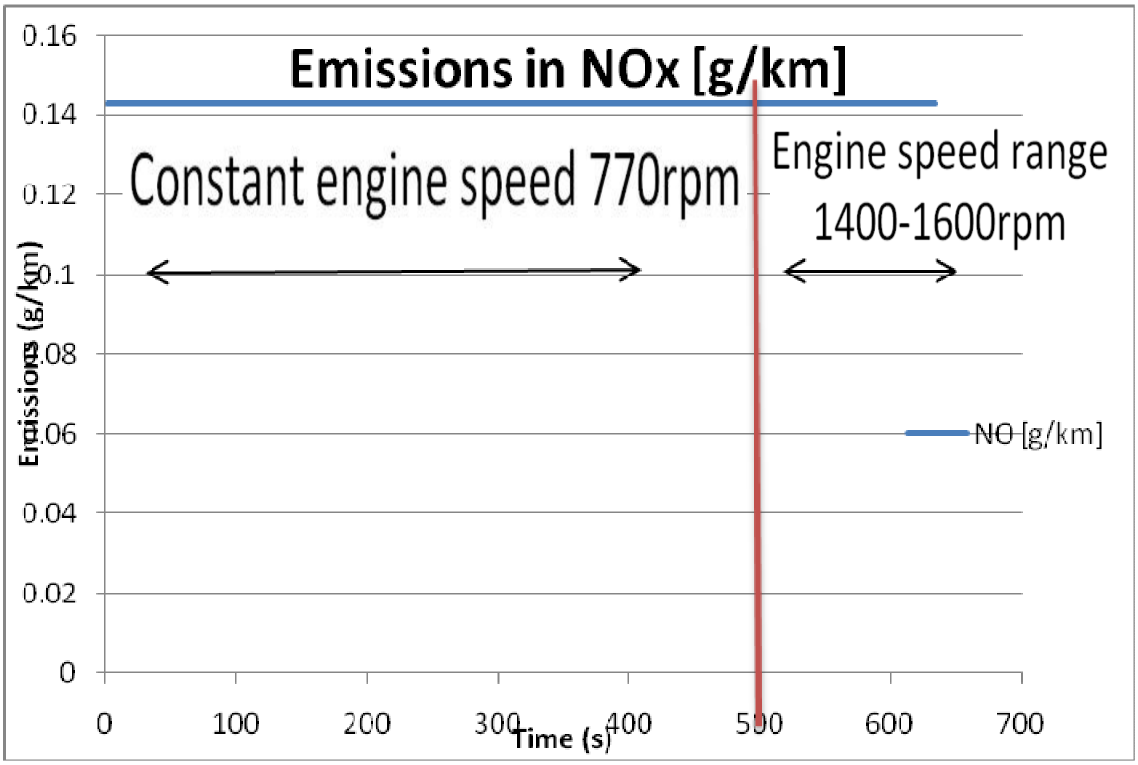


Figure 4.4: Nitrogen Oxide Emissions of Standstill Testing

A case can be made that the cause of high emissions of CO and HC was due to mechanical failure. The primary cause of high CO was that the engine is receiving more fuel than it can burn. With CO increasing, HC also increase while CO_2 and NO_X decrease. CO values should remain constant unless there is an increase in engine speed as seen with the test above. An increase of engine speed can mean that there is a problem within the vehicle such as a vacuum leak or fuel control problem.

Mechanical failures are also the main reason for high HC emissions. It is known that all engines produce some hydrocarbons, usually around 150 – 250 ppm before catalytic conversion. Some causes of HC emissions are fuel delivery, engine mechanical and electrical problems or catalytic conversion problems. The reason that all mechanical failures can be ruled out within the system is that it is known that NO_X emissions values should be high and constant during idle running. This is the case with figure 4.4 and therefore any mechanical failures in the system can then be ruled out. It is also worth noting that the amount of NO_X produced is very low in comparison to other emission and can therefore be said that the amount of emissions for NO_X during standstill testing are negligible in comparison to HC and CO produced for the same test.

4.1.2 DCU campus test (short urban route)

The only emissions that will be taken into account are CO and NO_X during the short urban route. It was noticed from the results that some of the independent driving pattern factors have a significant effect on fuel consumption and emissions in urban areas. From figure 4.5, it is noted that the amount of CO produced is significantly greater than that of NO_X. While this result was expected, the amount of CO produced was quite unexpected. The pollutants emitted an average of NO_X is 0.22898 gram per kilometre and an average CO produced is 3.37 gram per kilometre. This is over a distance travelled of 4.442 kilometres. It is noticed from the results that the amount of total CO produced through exhaust emissions for short urban use is nearly 15 times the total amount of NO_X produced. The total amount of NO_X and CO produced over the distanced travelled is 1.01715 grams and 14.97135 grams respectively.

Emissions produced during braking were reduced. During stopping very little emissions were produced. However, it is interesting to see that the emissions behaviour was very different under the same conditions. From the tests it is known that there were 2 stops. The first stop was taken at 150 seconds and the second at 350 seconds. After the first stop there was a gradual increase through gears up to the 4^{th} gear. This means that all gears where engaged for at least 20-30 seconds up until the next shift. It can be sent through this method that there is a steady increase of the CO emissions where as the NO_X emissions seem to increase rapidly during the intermitted stages. At a high gear, the emissions of CO are considerably higher than those of NO_X. However the emissions of NO_X are noticeable higher at low revolutions and low gear than the emissions of CO. Figure 4.6 shows the emissions relative to one another. NO_X and CO emissions are produced under similar conditions.

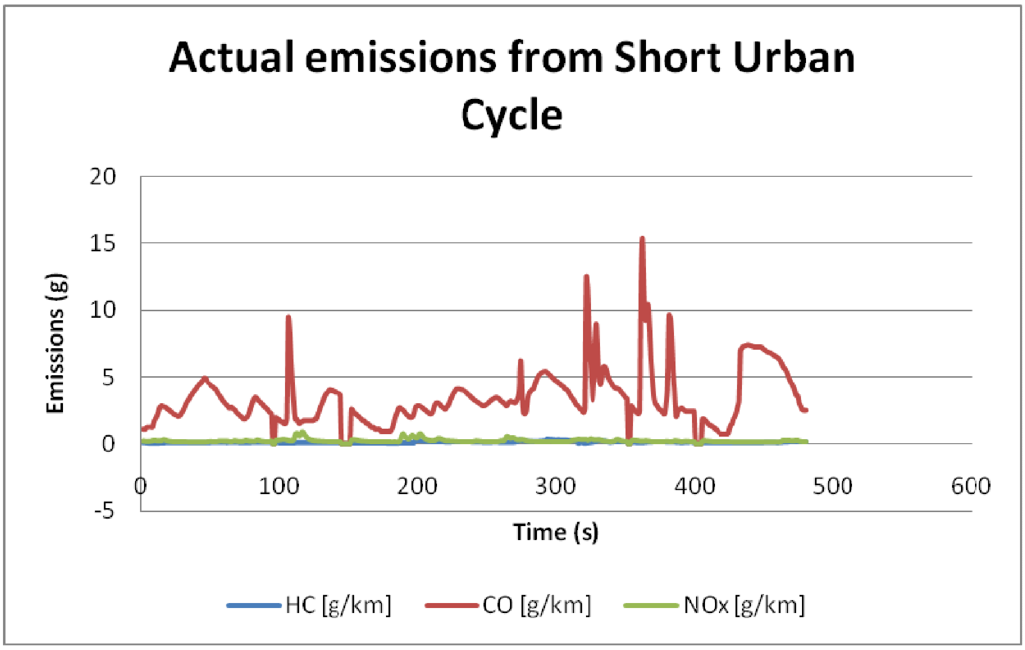


Figure 4.5: All emissions from Short Urban Route

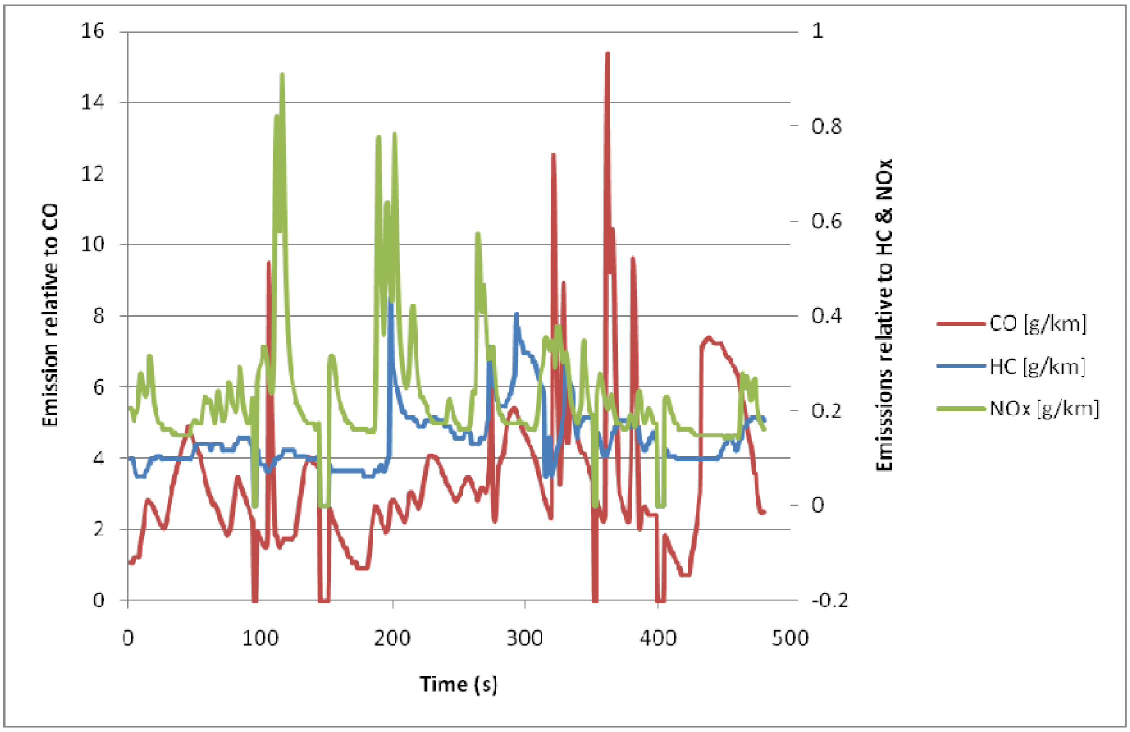


Figure 4.6: Emissions relative to one another

It can be seen through the breakdown of both NO_X and CO seen in figures 4.5 and 4.6 just how the driving performance effects emissions. For instance, the stop at

350 seconds is followed by quick acceleration through gears. Each gear was selected for the minimum amount of time which in some cases was less than 5 seconds. Figure 4.6 shows a comparison of how this behaviour has impacted on emissions as seen that the amount of NO_X produced has a sharp increase after takeoff but once 4th gear is reached there is generally very low emissions. This is in stark contrast to CO as once a high gear is reached; there are generally large amounts of CO emissions.

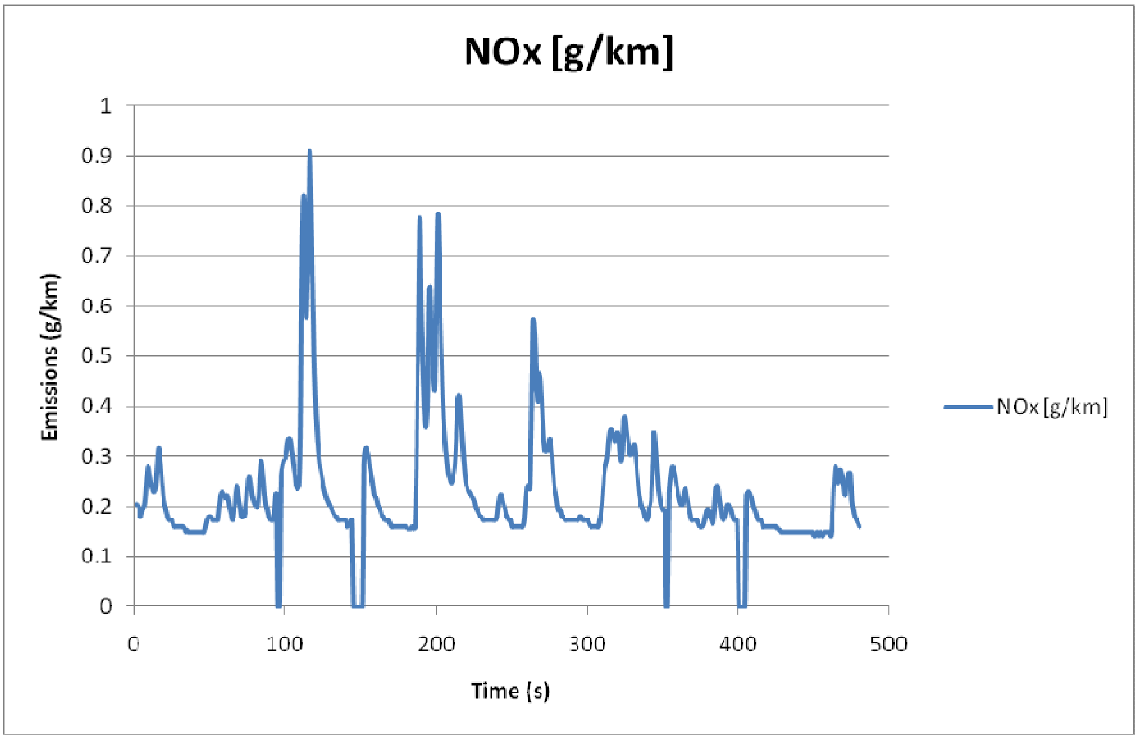


Figure 4.7: Breakdown of NOx emissions

During each phase of driving, the emissions follow a similar pattern. The only difference between the emissions is the quantity of total emissions produced. It was important to highlight that there is a small difference between the two emissions produced at one stage. This occurs after 400 s when one emission increases while the other is decreasing. In this time period, it shows at one instant that an increase in CO is coupled with a decrease in NO_X. There is no obvious reason for this but it is a concern. This pattern may be due to a driving error made at this one point such as the clutch and accelerator pedal being pressed at the same time. This could indeed cause an increase in engine speed but this action should be followed by NO_X remaining constant and CO increasing. However this is not the case. Also it shows that there is some uncertainty within the actual emissions and will have to be analyzed at a later stage.

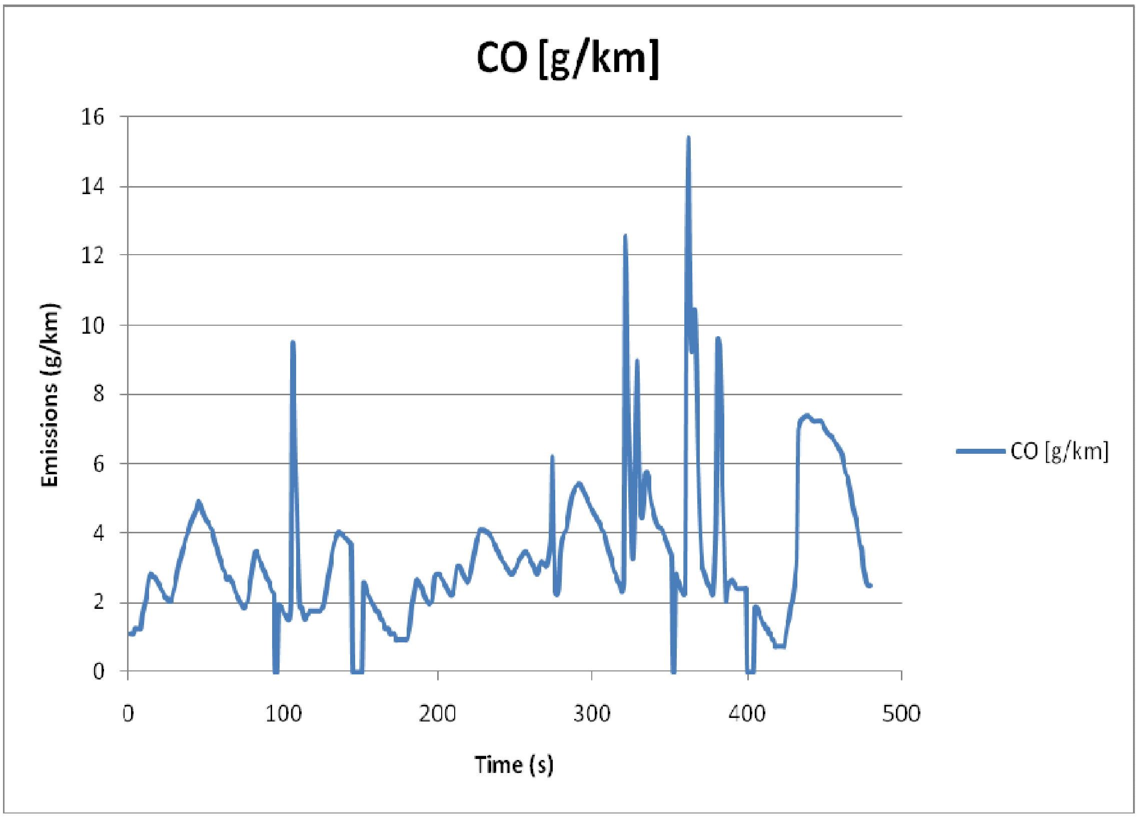


Figure 4.8: Breakdown of CO emissions during Short Urban Cycle

In general, it can be seen that all emissions follow a certain pattern. During gear up shifts (for example from 3rd gear to 2nd gear) and an increase in engine speed there is an increase in all emissions. The same can be said for gear down shifts and speed decreases where there a decrease in emissions.

4.1.3 DCU-Motorway test

Traffic conditions usually vary from city to city but in most cases, certain assumptions can be made about areas which are present in every city. Therefore, classification of traffic conditions is needed. Classifications can be made depending on the micro-trips in regards to the average speed and percentage of idle time with each trip. Traffic conditions will be categorised by idle time versus average speed as shown in table 4.2. The different traffic conditions are defined as *urban conditions* and *motorway*:

Urban Conditions: Traffic flow that consists of non-free flowing traffic with frequent stops. Low to moderate average speeds from 10 km/h to 35km/h are associated with these traffic conditions.

Motorway: Free flowing traffic with average speeds above 40km/h.
By applying these thresholds, the classification used for traffic conditions may be illustrated as shown in table 4.2

Table 4.2: Classifications of Traffic Conditions.

Classification	Average Speed (km/h)	Idle Time (%)
Urban	10 – 35	<80
Motorway	>40	<10

The test included four types of cycles at four different routes. Figure 4.9 shows the driving cycles given over the route. The speed is broken into four sections. These sections are given from the classifications mentioned in table 4.2. However, it is worth noting that cycle 1 and cycle 2 do not conform to usual urban classifications. These areas have high speeds and relatively little stops, yet cannot be classified as motorways but may be considered as an extension to or from a motorway. These routes may be considered as extra urban routes due to their high speeds relative to urban characteristics.

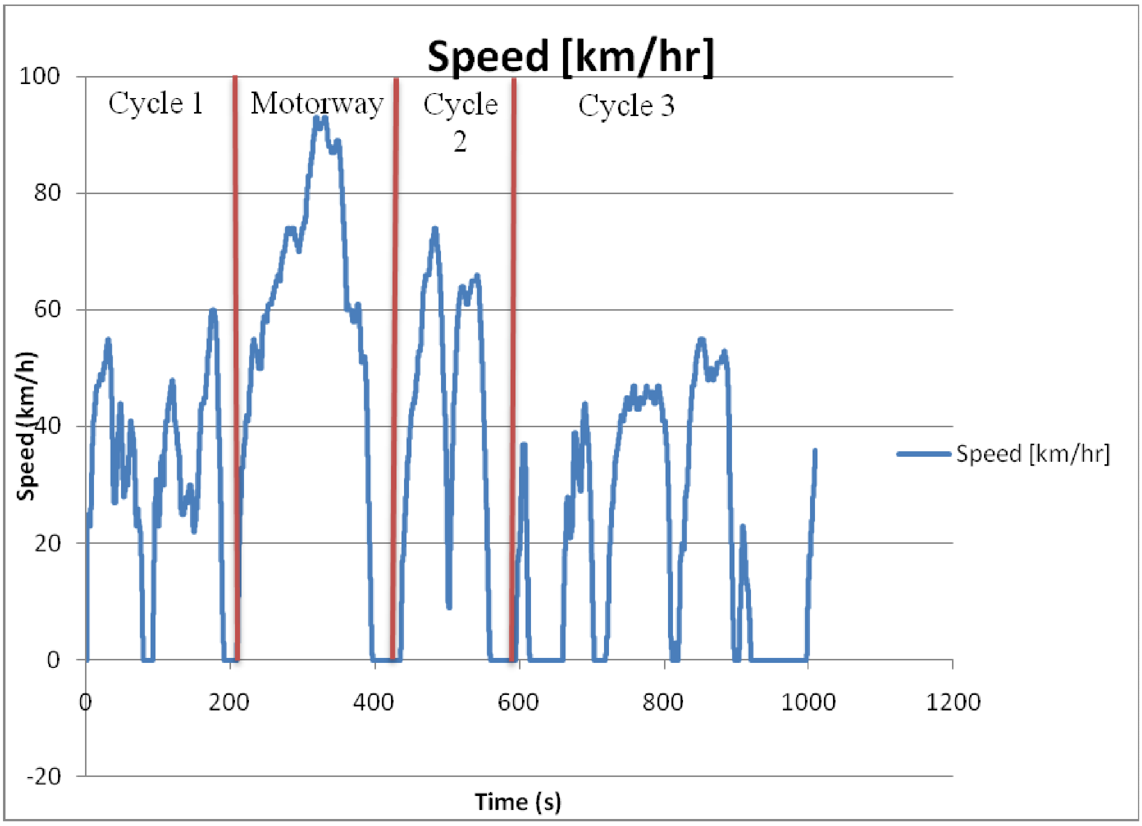


Figure 4.9: Speed during Estimated Test with brake up of cycles

From figure 4.10, it can be noticed that during the motorway cycle, it appears that most of the pollutants are emitted during this cycle. The other cycles seem to have a lower estimated emissions value during a similar distance travelled than the motorway. However when the data was analyzed, this was not the case. The total CO and NO_X emissions were estimated to be 1.572 grams and 0.175 grams over a distance close to 6 kilometres. The average of these estimated emissions where 0.2022 grams for CO and 0.0384 grams in terms NO_X.

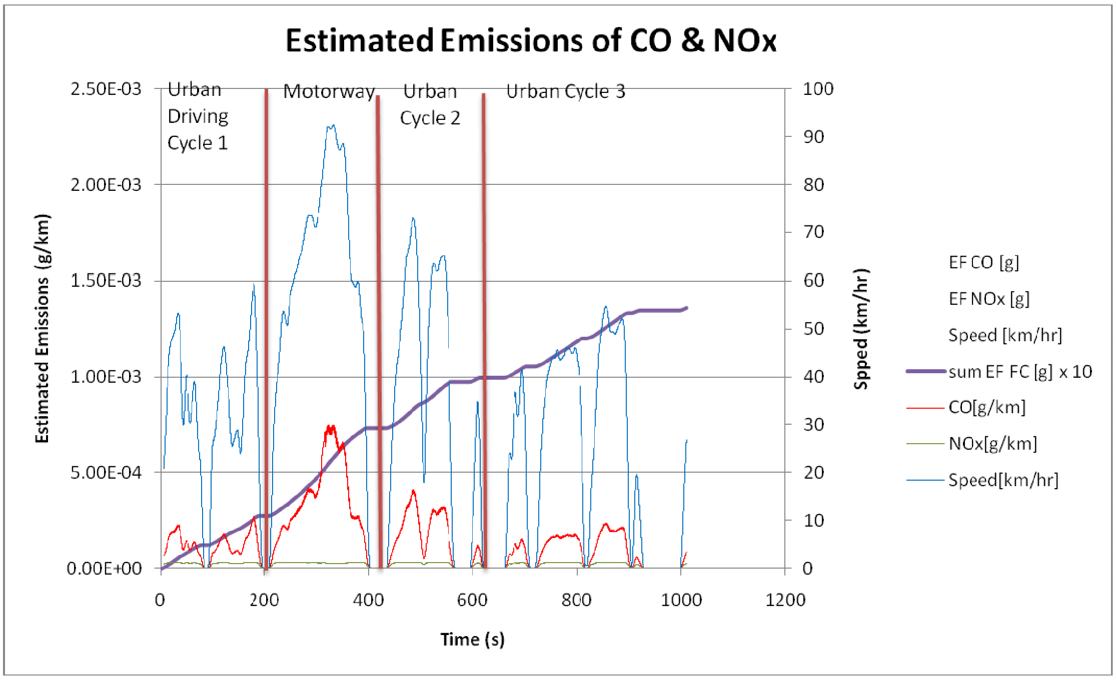


Figure 4.10: Estimated Emission graphed against speed

Figure 4.10 subdivide the motorway and urban sections to compare the estimated emissions. The average estimated emissions on the motorway for CO and NO_X were 0.000347 grams and 0.0000265 grams respectively. This also takes into account the hot emissions equation to find the values for CO and NO_X. The values of the corresponding urban route show that the emissions for CO are 0.00085 grams and projected for NO_X are 0.0000184 grams. This shows in general that a motorway travelled with higher speeds should in theory emit fewer emissions than that of a corresponding urban route of a same length. This backs up the theory that at a constant speed fewer emissions are produced. It is the stop-start nature of the urban routes which contribute to increased fuel consumption in these types of road set-up and this in turn leads to a higher emissions produced on average than that of the motorway.

4.2 Comparison of results

4.2.1 DCU-Dundrum tests

Long urban and motorway driving cycles were both under investigation in this test [107]. Figure 4.11 and Figure 4.12 show the driving cycles obtained from both trips. The trip via city centre (Urban driving cycle UDC) was full of stops and vehicle speed was up to 74 [km/hr], while the trip via motorway (Extra-Urban Driving Cycle EUDC) had few stops and the speed reached 100 [km/hr] many times.

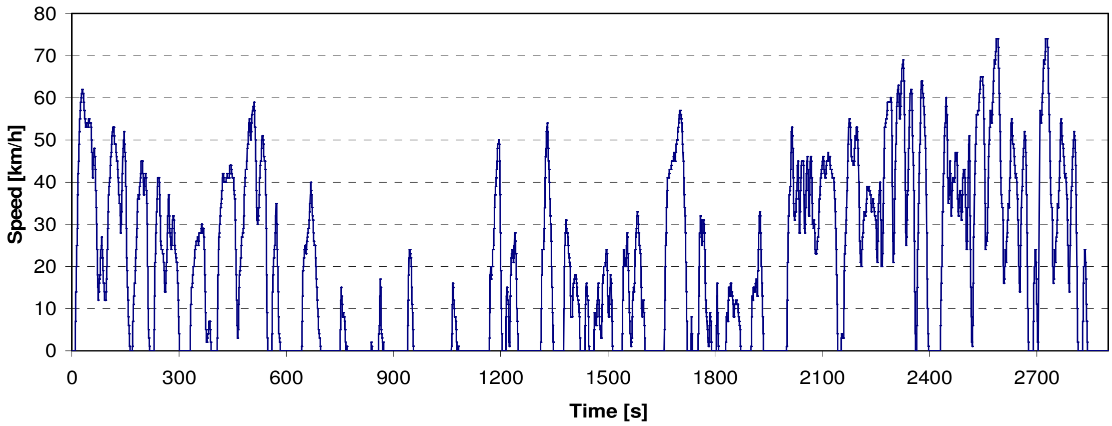


Figure 4.11: Urban Driving Cycle

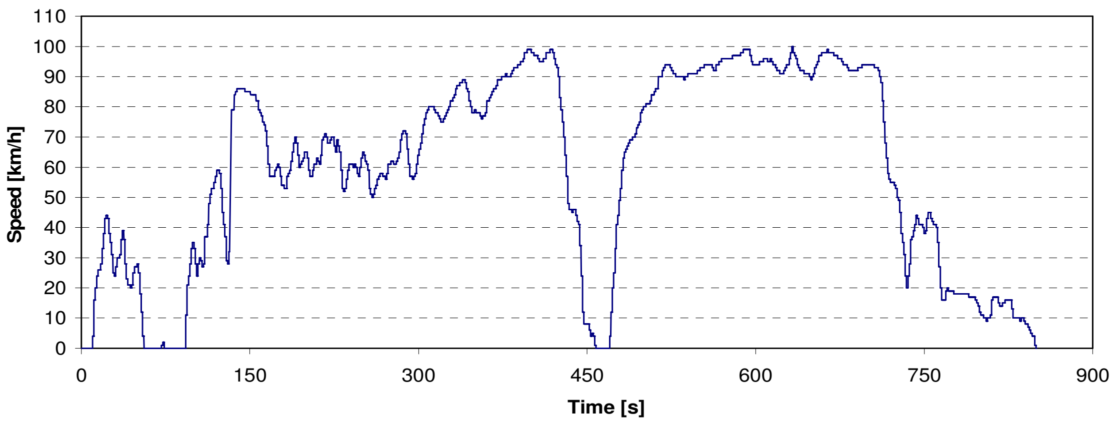


Figure 4.12: Extra Urban Driving Cycle

After setting up the driving cycles for the two routes, CO and NOx emissions as well as total fuel consumption (FC) are all in gram per kilometre. These parameters are calculated by equation (3.6) using the related coefficients of the passenger car used. These coefficients were obtained from COPERT hot emission parameters which can be used as European standards for model, year, engine capacity, and legislative standard of the vehicle. Having this done, all emission factors have been converted into gram per unit by using the following formula:

$$EF_{n,k} = EF_{n,k} * V_k * \Delta T_k/3600 \quad (4.1)$$

Where:

$EF_{n,k}$: emission factor with n, in gram per kilometre over time k

Vk: vehicle speed in time k.

ΔT_k: period of time between two points.

Figure 4.13 and Figure 4.14 show the CO and NOx emissions with total of fuel consumption (FC) all in gram per kilometre for both of the driving cycles.

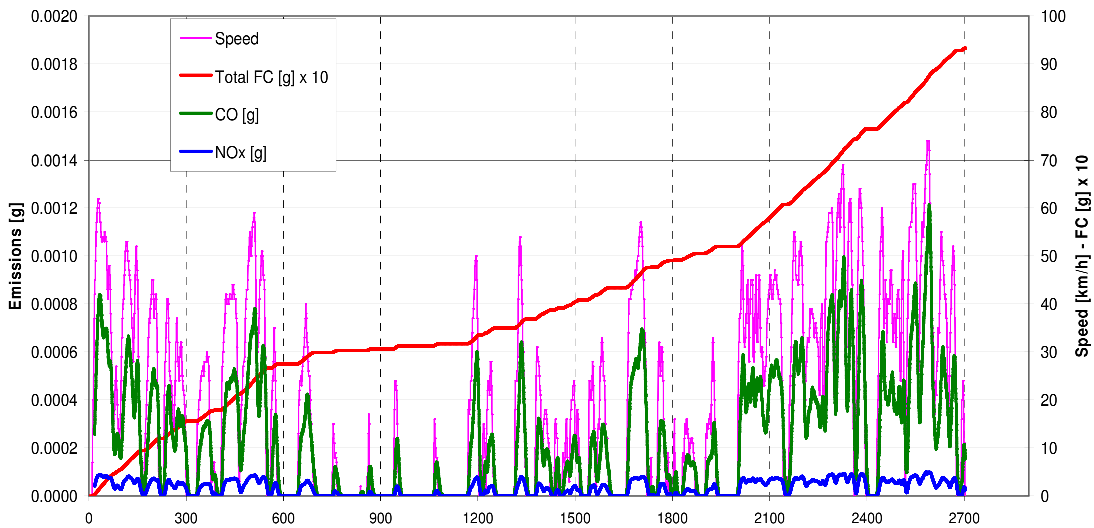


Figure 4.13: Emissions for Urban Driving Cycle

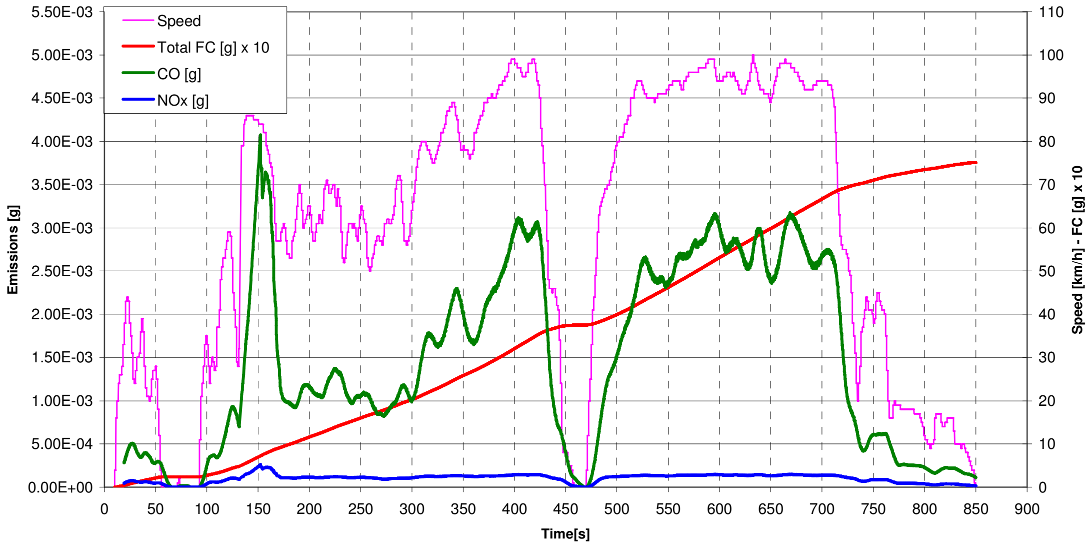


Figure: 4.14: Extra Emissions for Urban Driving Cycle

A comparison between these two cycles of 14 km has been made. The first trip took 2703 s and the average speed was 19.547 km/hr. The second trip took 850s and the average speed was 59.6 km/hr. CO emissions, NOx emissions, and fuel consumption for both trips were compared in terms of average emission per second [g/s], average emissions per unit distance [g/km], and total emission [g/trip] as mentioned in Table 4.2.

It was found that NOx emissions and FC are less in EUDC cycle than in UDC cycle while CO was more in EUDC. Gas analyzer1was involved in these tests for the validation of these emission values as it is shown in appendix C

Table 4.2: Comparaison between UDC and EUDC in termes of CO, NOx, and FC

	Urban Drive cycle Distance travelled = 14.678 km Average Speed = 19.547 km/h Time = 2703.3 seconds				Extra-Urban Drive cycle Distance travelled = 14.073 km Average Speed = 59.614 km/h Time = 849.9 seconds		
	CO	NOx	FC		CO	NOx	FC
Average Emissions per second [g/s]	0.003	0.0004	0.345		0.014	0.0010	0.884
Average Emissions per Unit Distance [g/km]	0.544	0.076	63.59		0.837	0.059	53.38
Total Emissions [g/trip]	7.990	1.112	933.3		11.776	0.826	751.2

4.2.2 Home-Work tests

CO and NOx has been calculated individually for each time step using equation (3.6), and then accumulated in order to extract the average EF:

$$\text{Ave EF} = \sum \text{EF}(n) / N \qquad (4.2)$$

where EF (n) is the emission factor each time step, and N is the number of time steps.

The total EF would become:

$$EF_{total} = \text{Ave EF} \times \text{Distance travelled} \qquad (4.3)$$

NOx emission has been calculated by the same steps mentioned above [109].

Table 4.4 displays the average time taken by each route for the tests in the times indicated. On testing, some errors had occurred. To obtain a sufficient number of reliable results, 18 tests had to be taken to achieve a representative driving cycle for Dublin city and estimate vehicle emissions from this driving cycle in place of the European driving cycle (EDC).

Table 4.4: Average test route times

Time	8:00 – 10:00hr	16:00 – 18:00hr	21:00 – 22:00hr
Route 1 [min] Avg	33.9	20.77	10.68
Route 2 [min] Avg	13.65	33.45	12.92

Figure 4.15 shows one of the 18 driving cycles obtained during the night-time period of route1. Speeds up to 55km/hr and significantly less stops from the other two periods (morning and afternoon) are noticed.

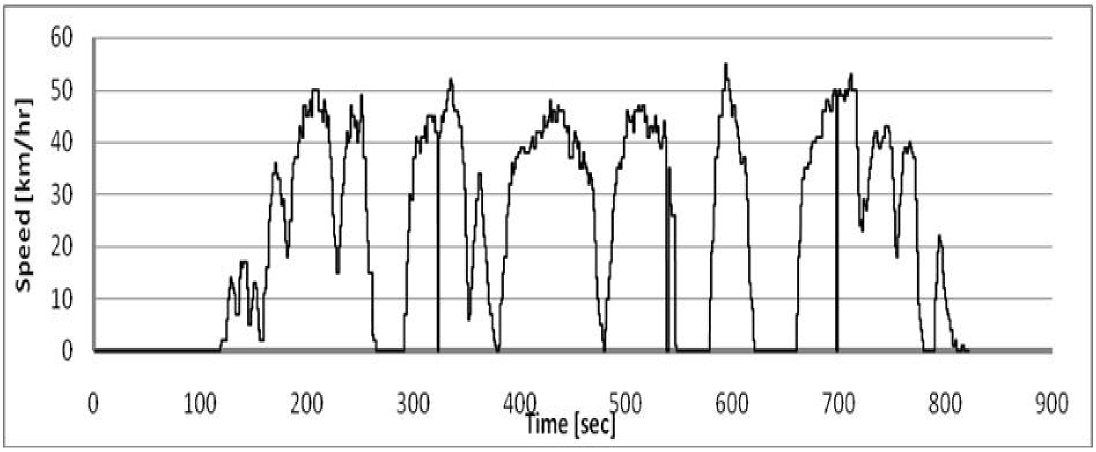


Figure 4.15: Dublin Driving Cycle (DDC)

Figures 4.16 and 4.17 show the emission factors extracted from the Dublin driving cycle by applying the equation (3.6) and formula (4.2) by using the proper parameters for each emission factor from COPERT4. It was considered that only hot emissions are coming out from the car as the engine was working 15mins before start the trip in order to ignore the cold emissions in the estimations.

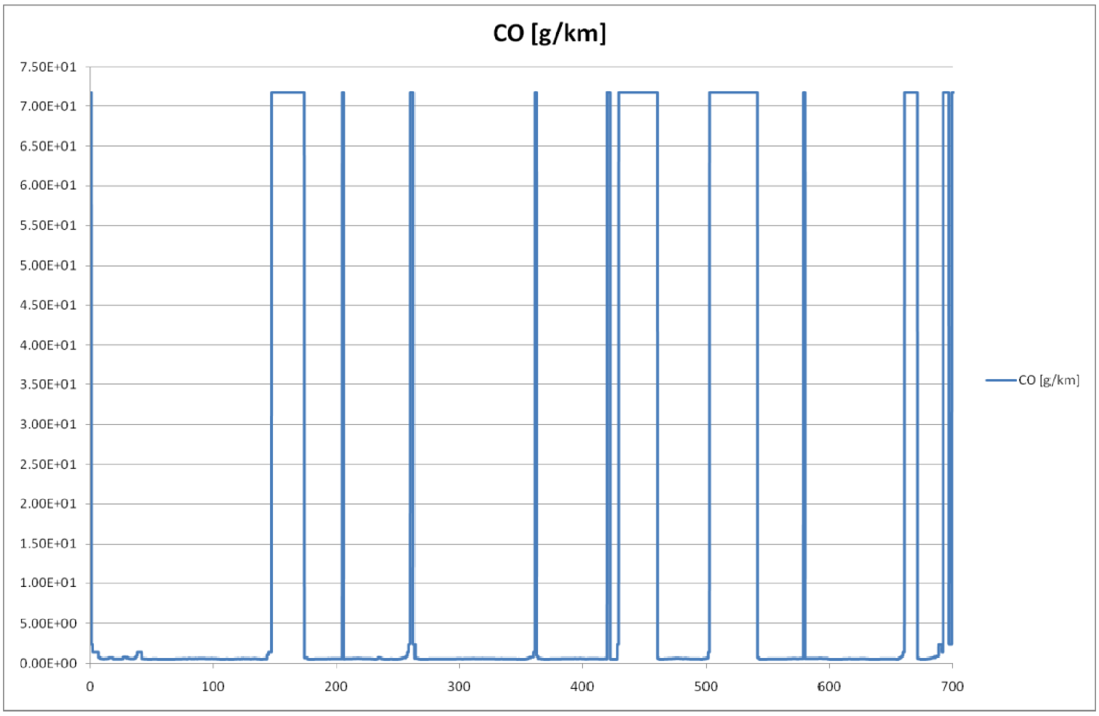


Figure 4.16: CO emissions estimated from DDC

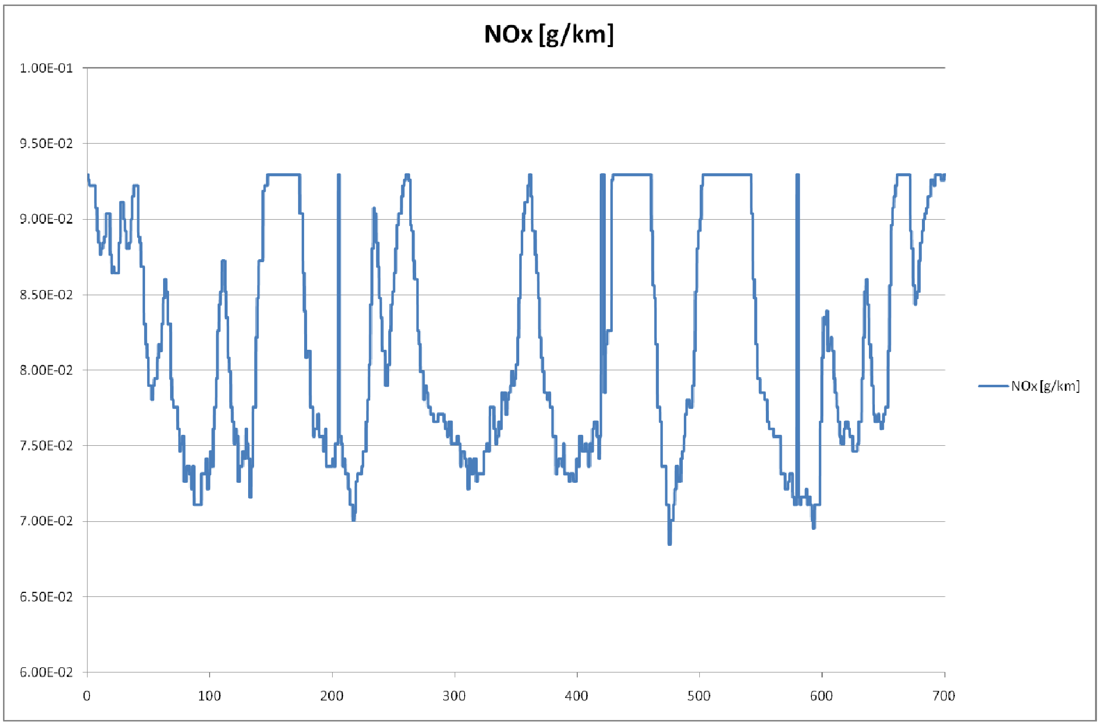


Figure 4.17: NO emissions estimated from DDC

At the same time, a gas analyzer was in the car with separate small screen that was monitoring the data and saving data every second in an excel file. This device stores the data for a maximum of 20 minutes. After the 20 minutes of recording, the device is reset to save new data. It is for such reason that a short time trip (less than 20mins) was recommended to obtain accurate measuring.

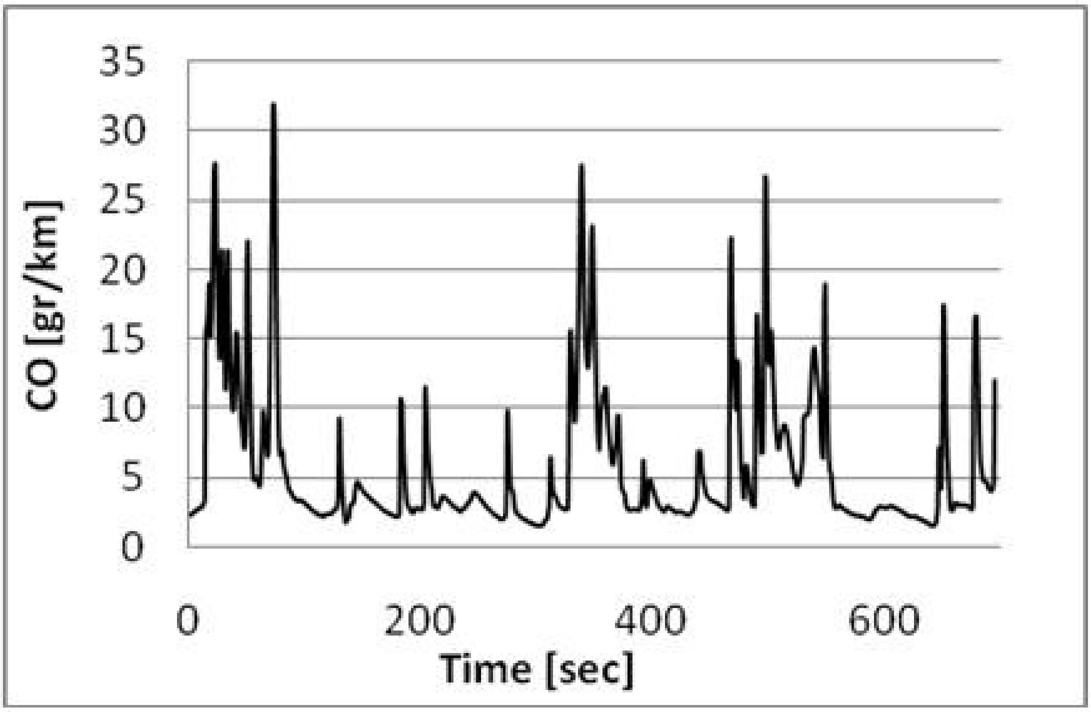


Figure 4.18: CO emissions from Gas Analyzer

The gas analyzer stores the emission factors in two different ways, either in Vol% and ppm, or in gram per mile. Figures 4.18 and 4.19 show the emission factors after conversion into gram per kilometre.

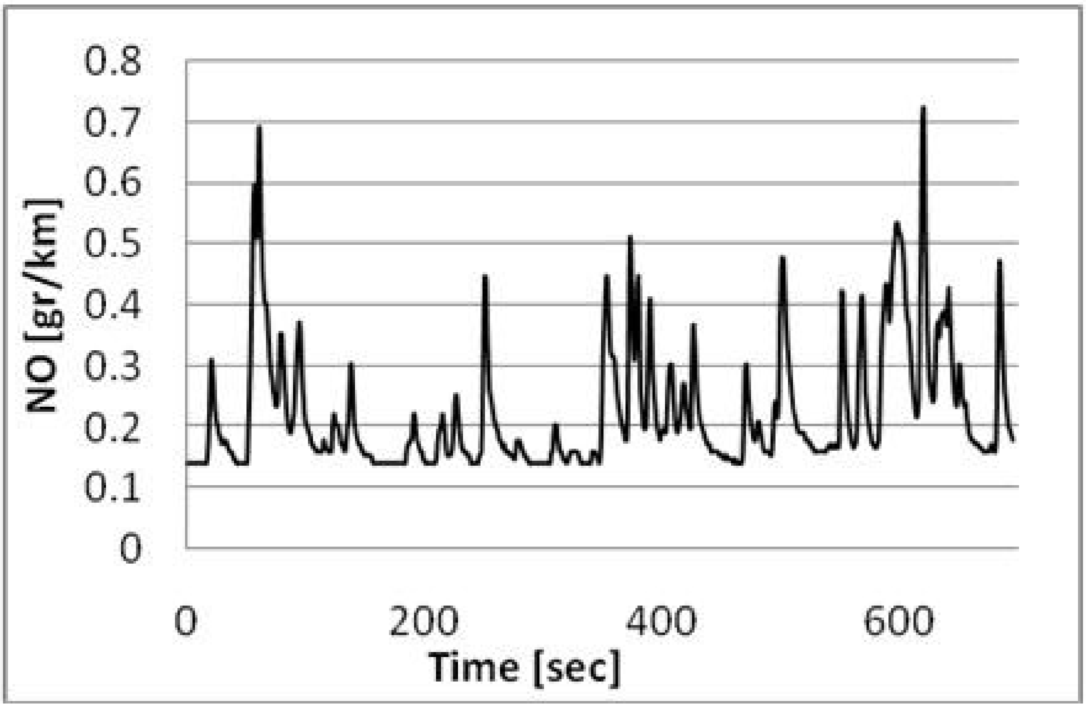


Figure 4.19: NO emissions from Gas Analyzer

In order to obtain the total emission factor for both CO and NO from the estimated method, the average vehicle speed [km/h] was calculated and employed in the same equation (3.6) to get the average emission rate [g/km] for both emission factors. These calculations were then multiplied by the distance [km] travelled during the trip. While in the measuring method, it was only needed to multiply the emission rate for both emission factors by the distance for the trip.

Table shows the comparison between both methods. The results obtained in this experimental study have shown a noticeable deviation between the COPERT 4 theoretical CO and NO emission factors calculated and the actual values. It has been found that the CO estimation was overestimated while NO was underestimated. For this reason, the emission variations has been investigated and compared to vehicle speed using equation (3.6) for a Euro 3 legislative standard car which has the coefficients set up for the tested car by COPERT methodology.

Table 4.5: Comparison between measured and estimated emissions.

	Measured	**Estimated**
NOx [gr/km]	1.136	0.420
CO [gr/km]	28.66	66.48

In order to investigate the differences in CO and NOx emissions, two graphs have been plotted for the two emission factors in term of vehicle speeds [109]. Figures 4.20 and 4.21 show the EF variations for vehicle speed from zero speed to 100km/hr.

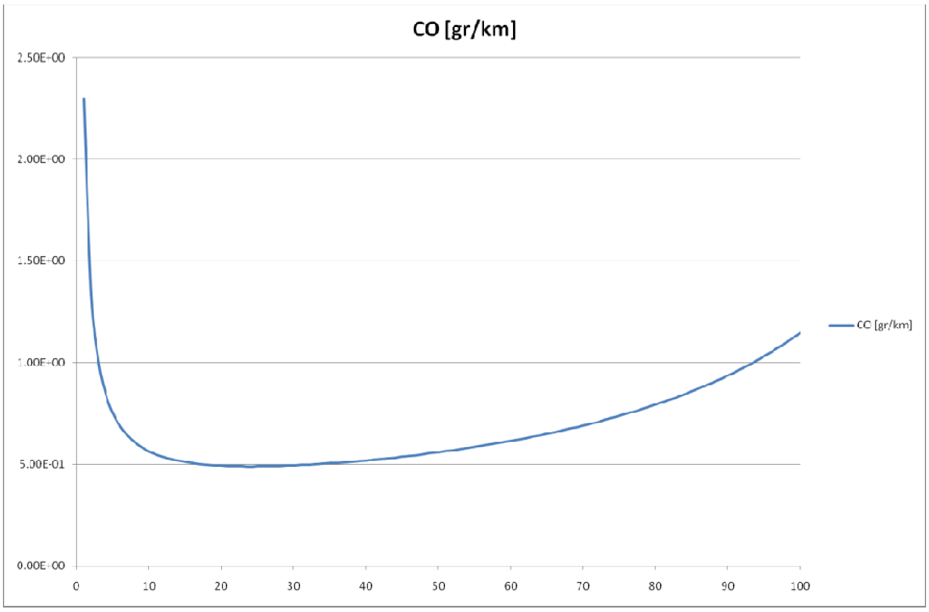


Figure 4.20: CO vs Speed in COPERT methodology.

It was found that CO has a significant emission number when the car on the idle time (zero speed) which covered 17% of the total test time. That led to a noticeable difference in real emissions. In relation to NO_x emissions, the variation was slightly different among speed steps including idle time.

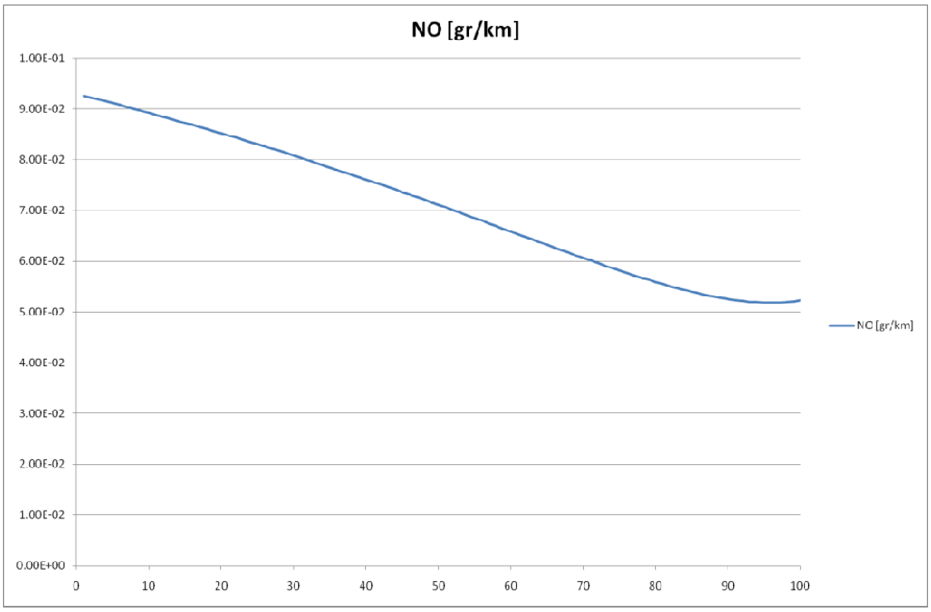


Figure 4.21: NOx vs Speed in COPERT methodology.

Table 4.6 shows the critical car speeds for CO and NO_x variations. In relation to CO, if idle time was excluded from the total time, CO emission would be underestimated.

Table 4.6: the critical car speeds for CO and Nox variations.

Speed [km/hr]	0	1	25	96	100
CO [gr/km]	71.7	2.3	0.49	-	1.15
NOx [gr/km]	0.0929	0.0926	-	0.0518	0.0523

4.3 Aleppo results (third stage)

4.3.1 Establishing a preliminary driving cycle for Aleppo City

Three optimum trips were chosen for peak hour time (home-work phase) as shown in Figure 4.22.

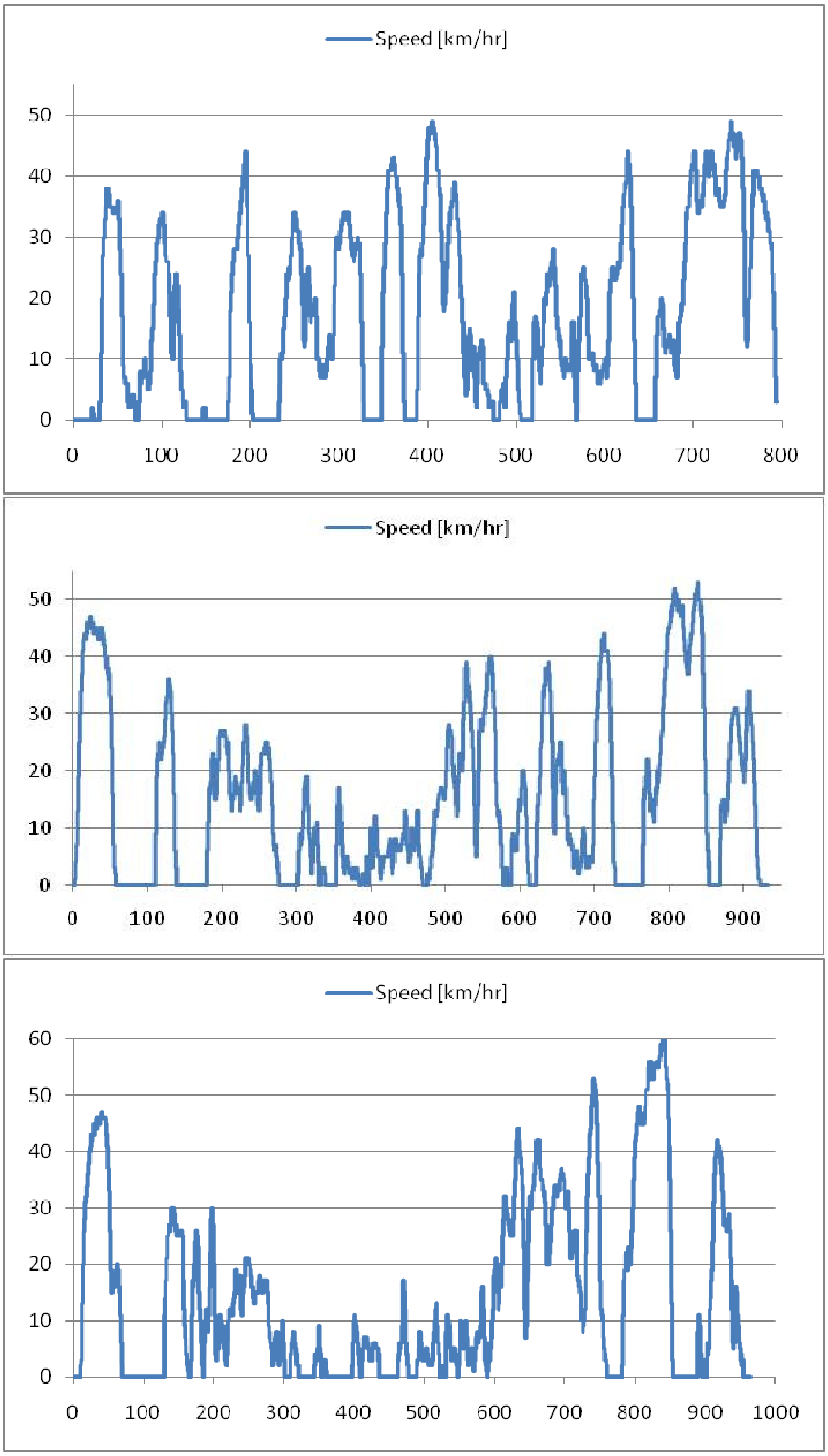


Figure: 4.22: Three Optimum trips for peak hour [time vs speed].

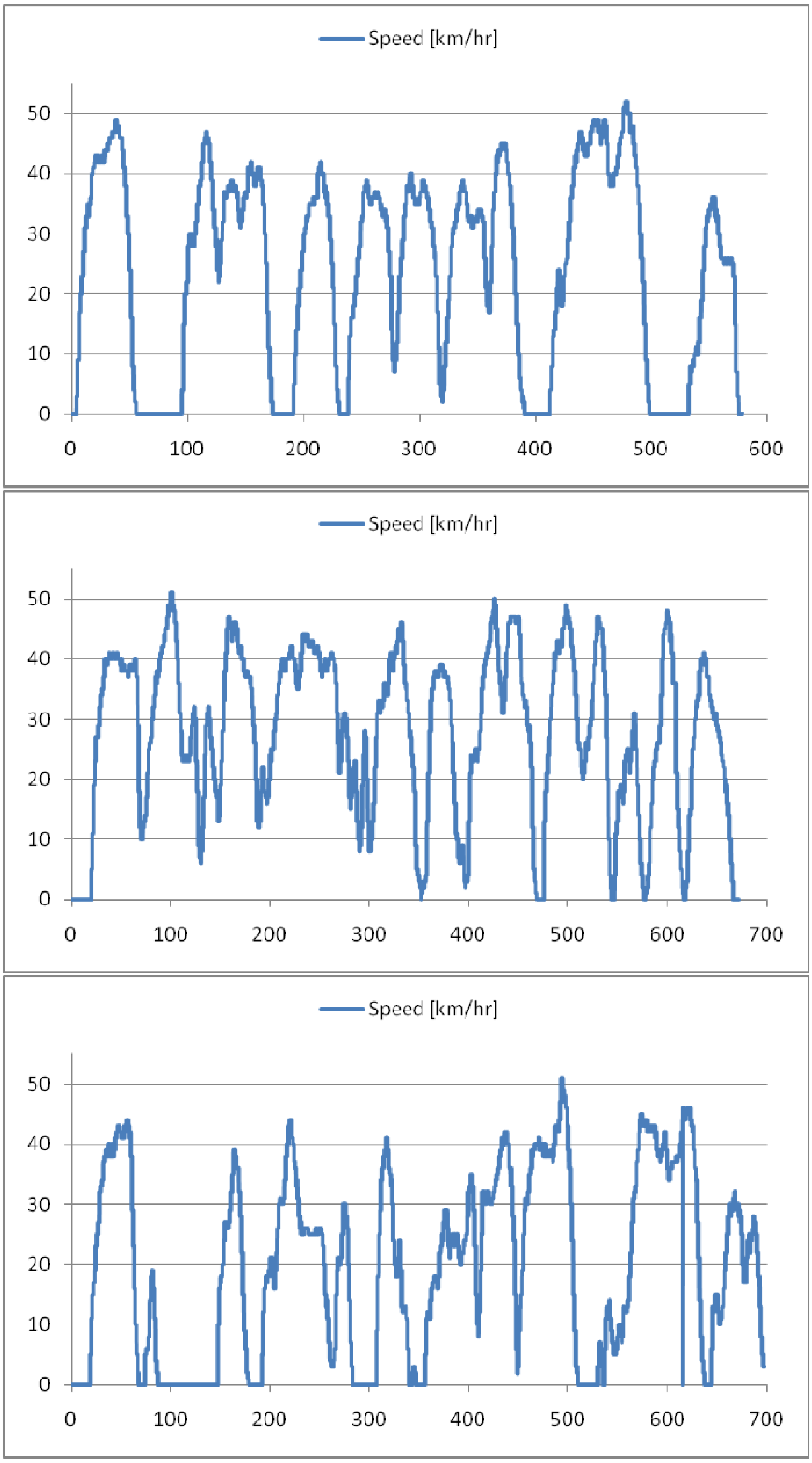


Figure 4.23: Three optimum trips of evening time [time vs speed].

It had been distinguished that the maximum speed reached was 55km/hr and the maximum stops were 15 times in one trip. The trip map was chosen depending on traffic congestion levels and distance from city centre [110]. The streets tested were between city centre and Aleppo University which has around 130,000 students on campus. On testing, some errors had occurred. A sufficient number of tests were performed to achieve the representative driving cycle for the city. Figure 4.23 shows the three optimum trips for the evening time mode.

4.3.2 Phase2: Assessing Energy Consumption of the Aleppo driving cycle.

Figs 4.24 and 4.25 show the driving cycles obtained from both peak hour and off-peak hour trips. The trip in the peak hour consisted of many accelerations and decelerations, and the average speed was 28.72 km/hr. However, the trip in the evening time is less in comparison where the speed reached 32.22 km/hr. There were three traffic lights on the road, but the driving mode was not smooth because of the density of the cars in both trips [111].

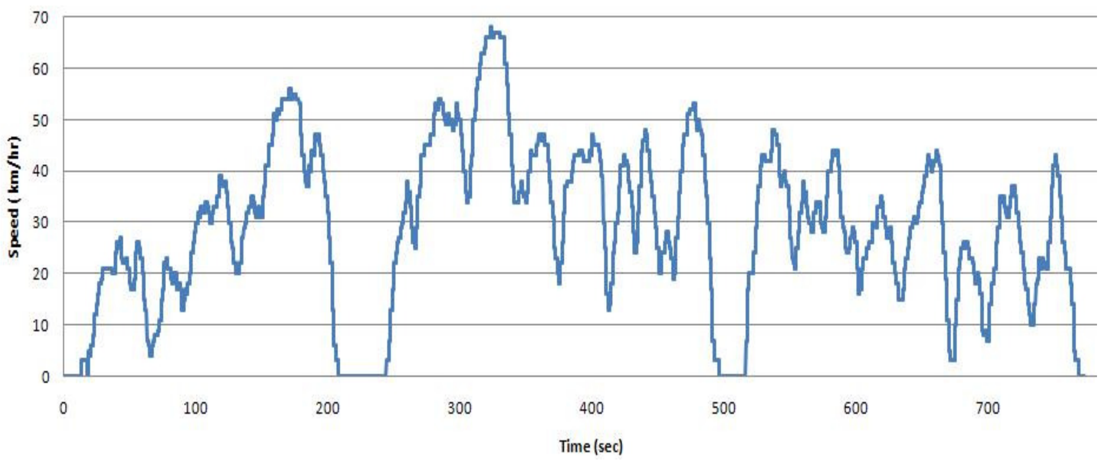


Figure 4.24: The Driving Cycle in the peak time (phase 2).

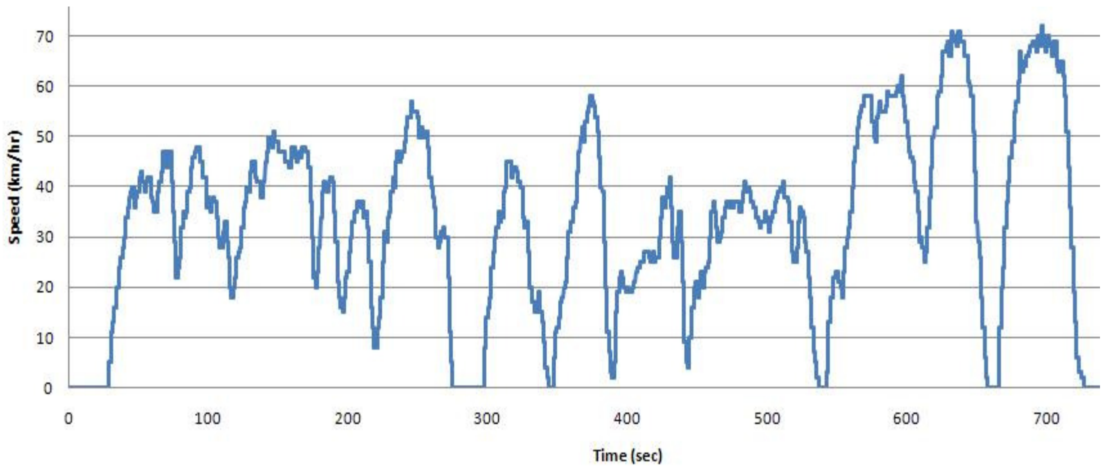


Figure 4.25: The Driving Cycle in the evening time (phase 2).

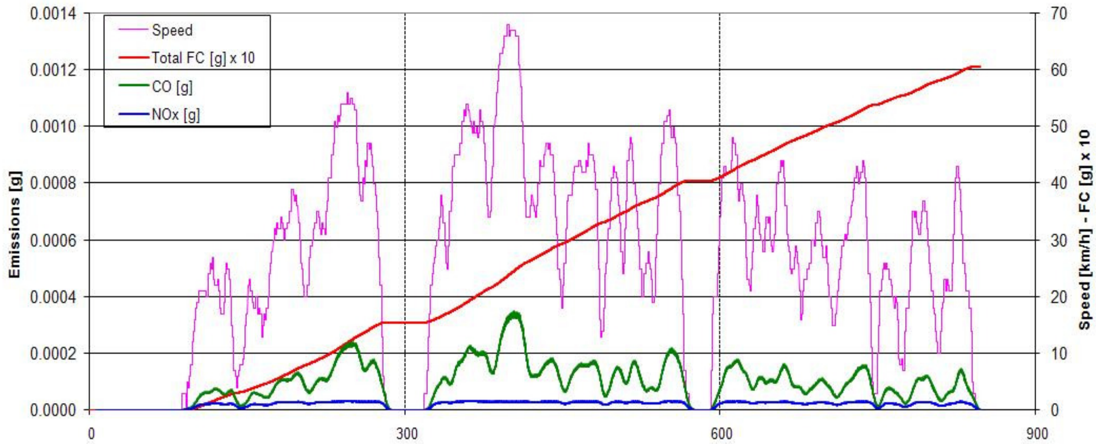


Figure 4.26: Three optimum trips of evening time [time vs speed].

Fig 4.26 shows for the Aleppo driving cycle in peak hour for CO and NO_x emissions [g/s] as well as the fuel consumption (FC) [g] calculated by equation (3) using the related coefficients of the passenger car used. These coefficients were obtained from COPERT hot emission parameters which can be used as European standards for make, year, engine capacity, and legislative standard of the vehicle [15].

Table 4.7 shows the average emission factors of the trip which were obtained from the COPERT equation after applying the average speed.

Table 4.7: The average speed, CO, NOx emission, and FC.

	Speed [km/hr]	CO [g/km]	NOx [g/km]	FC [g/km]
Average	28,27	0.1743	0.0499	104.6885

Table 4.8 shows the total emission factors of the trip when adding the entire emission factor obtained per second.

Table 4.8: Total emissions obtained from the trip.

	CO [g]	NOx [g]	FC [g]	Time [sec]	Distance [km]
Total	1.201	0.268	606.651	848.28	6.175

4.4 Methodology used in the study

There are many methods to measure harmful emissions that are being produced by vehicles into the earth's atmosphere. The experimental OBD method which was used in this study contains a signal interpreter "the ElmScan 5" along with configured "LabVIEW" software to produce a drive cycle of speed vs. time. It is now possible to monitor a range of engine signals such as drive cycles, emissions and fuel consumption in real time.

This data can be visualized via a PC attached with the tools in the form of graphed data plots. The results obtained from this package estimates these plots in real time using OBD signals. The use of this software reduces the need for bulky expensive analysis equipment and provides quick and accurate emissions estimates of the European regulated emissions (CO, HC, NOx and particulate matter). The advantage of this method is that it can be used in anywhere in any country using portable equipment that can fit easily in the back seats of the car without affecting driver behaviour or putting people's life to any danger Figure 4.27.

Figure 4.27: OBD scan tool connected to both car and laptop.

The use of the Autologic Gas analyzer indoor or on the road came as an effective method for emission estimation. The small size has a large advantage over larger bench testers which are very expensive. This is ideal for the ease of research and development in the field of emission measurement. The kit comprises of 15 individual pieces when connected to the laptop and vehicle exhaust pipe. The kit can also instantaneously measure 5 different emission gases.

The analyzer emission sample probe is prone to choking up with carbon deposits which can give misleading results to the researcher. To counteract this problem, a calibrator is installed in the second Autologic package which cleans the various gas sensors, probes and ports to maintain accuracy. The analyzer is suitable for durable environments to diagnose engine emission problems. The analyzer is capable of measuring up to 5 separate gas types (HC, CO, CO2, O2, NOx), lambda and Air/Fuel sensor measurement. The software provides a display using a plug and play set-up easily used with any car with a car cigarette lighter installed to run the analyzer if an external battery is not provided with or drained.

The disadvantage of the tool is that it needs regular maintenance such as replacing the water trap filter monthly or before if it is used extensively, figure 4.28. This procedure is easy to carry out but is sensitive to filter location.

Figure 4.28: The water trap filter has been used and replaced (left image) with a newer version with the housing (right image).

Another issue is that gas calibration has to be done every six months and in a factory which is costly and ineffective in terms of research or project progress. The only reason this device was used is in order to evaluate the emission factors obtained from the estimation method.

Chapter 5 Conclusion and Future work

5.1 Conclusion

With respect to the control of air pollution, specifically from transport there is a need to establish a method to quickly and effectively estimate on-road vehicle emissions. The introduction of various methods such as determining emissions via the drive cycle using OBD software and theoretical COPERT 4 software have been designed to meet with this objective. These methodologies have been implemented in this project. Some points in conclusion needed to be clarified in this chapter as the study covered a widespread topic and used certain techniques during experiments:

- Portable reliable equipment at low cost was developed.

- It is now possible to monitor a range of engine signals such as drive cycles, emissions and fuel consumption in real time.

- Preliminary driving cycle for Dublin and Aleppo cites reflecting the real-world driving conditions were developed.

- Estimated vehicle emissions were achieved and compared.

- Provide local government in Aleppo city access to reliable tools that can accurately estimate the contribution of traffic related pollutant levels to local emissions inventories.

5.1.1 COPERT software

COPERT, one of most commonly a deployed tool has been used which makes use of bulk traffic movements and average vehicle speeds in order to estimate emissions. The combination of OBD data extraction incorporated in all modern passenger cars and COPERT emission factors have been employed. This approach takes real world vehicular activity into account in order to better estimate the contribution of private cars to local emissions inventories. The presence of the high factor considered in COPERT methodology for Euro 3 legislative standard passenger cars during idle time may be leading to the noticeable effect on the amount of emissions being considerably overestimated compared to the actual on-road emissions. Therefore, some kind of correction factor should be designed for representing the real-world vehicle emissions in order to improve the inventories used in different applications.

5.1.2 Emission estimation in developing countries

Due to the rapidly expanding and mobile populations in the developing world, the issue of low carbon development and transport needs to be urgently addressed. Syria was under investigation through this research in order to evaluate the traffic emissions in such a busy city and provide local government access to reliable tools that can accurately estimate the contribution of traffic related pollutant levels to local emissions inventories.

As each country has a unique driving cycle which represents the characteristics of the driving and the real amount of emissions from vehicles, individual testing is necessary for each region. A case study on the estimation of the emission values taken from a passenger car has been carried out. A representative driving cycle reflecting real-world driving conditions has been proposed and estimated vehicle emissions have been determined. The method was considered to be user-friendly and the results were shown to be accurate as real data from Aleppo city was used.
Pictures taken and data obtained from air quality stations as well as from experiments done in this research provide a clear idea about the transport sector in

a busy city like Aleppo in such a developing country. More investigation is needed and work has to be done in order to improve the transport sector in Syria.

5.2 Future work

Following on from the significant insights gained from the study presented in this thesis, the computational tools developed could be further improved and applied as follows:

5.2.1 LABVIEW configuration

The software seemed to be difficult to configure, with the initial configuration having to be manipulated many times before functioning correctly. Only after the help of LabVIEW, technicians and engineers was the format of the programme enabled to be used along with the OBD, communicator to obtain results. Access to re-writing this software is available as the original software was as a blueprint for any further development. More control and functionality could be added to the software programme for easy use.

GPS (Global positioning system) device is another option of use and it would be recommended to be used although GPS signals might not be available in some area due to trees or tunnels. Unfortunately GPS cannot be used in some countries such as Syria as it is against the law to use such this device.

5.2.2 Driving cycle and emission estimation

The driving cycle varies from even one city to another due to the type of principal activities present (industrial, agricultural). Individual testing is necessary for each region and results could represent the characteristics of the driving and the real amount of emissions from transport in order to establish a representative tool for the local authority in identifying the air quality in terms of traffic emissions.

References

[1] Khare, M. and Sharma, p., (2002), Modelling urban vehicle emissions, P3.

[2] "Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 on type approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information". Eur-lex.europa.eu. Retrieved 02/02/2011.

[3] http://www.scantool.net/elmscan-5.html.

[4] http://www.autologicco.com/gas.html.

[5] Heywood, John B., Internal combustion Engine Fundamentals, McGraw-Hill International Editions -1988

[6] Http:/Sstudent.britannica.com

[7] McGahan, Paul., PM, Estimation of On-Road Vehicle Fuel Consumption and Emissions using Analysis of OBD Signals, 4th Year Mechanical Engineering Project, BEng, 07/04/2006.

[8] Directive 98/69/EC of The European Parliament and of the council of 13 October 1998, Relating to measures to be taken against pollution by emission from motor vehicles and amending Council Directive 70/220/EEC

[9] http://www.obdii.com

[10] Barone, Stefano. Statistics-Driven Development of OBD Systems; An Overview, Quality and Reliability Engineering International, 2006, vol 22, 615-628

[11] Http://Expha.com

[12] www.euractiv.com

[13] www.dieselnet.com

[14] Sturm et al. Determinaton of Traffic emissions – intercomparison of different calculation methods, the science of the total environment, 189/190 (1996) 187-196

[15] www.acidrain.com

[16] Council directive of 20 March 1970 on the approximation of the laws of the Member States on measures to be taken against air pollution by emissions from motor vehicles (2004), European Union.

[17] Ludykar et al., Cold start emissions at + 22, -7 and -20 C ambient temperatures from a three-way catalyst (TWC) car: regulated and unregulated exhaust components, the Science of the Total Environment 235 (1999) 65-69

[18] Abdel- Rahman, A.A., On the emissions from internal combustion engines: A review. International Journal of Energy Research volume 22 (1998), 483-513

[19] www.meridianeng.com

[20] http://www.autocatalyst-recycling.umicore.com

[21] Pierson et al. C, Comparison of the SCAQS tunnel study with other on-road emissions data. Journal of Air Waste Management Association 40, 1495-1504

[22] www.isuzudieselengine.com

[23] Wang, Q., H. Huo, K. He, Z. Yao and Q. Zhang, "Characterization of vehicle driving patterns and development of driving cycles in Chinese cities", Transportation Research Part D: Transport and Environment, 13, 289-297, 2008.

[24] Hao Cai, Shaodong Xie, "Estimation of vehicular emission inventories in China from 1980 to 2005", Atmospheric Environment, Volume 41, Issue 39, December 2007, Pages 8963-8979

[25] Ludykar et al., Cold start emissions at + 22, -7 and -20 C ambient temperatures from a three-way catalyst (TWC) car: regulated and unregulated exhaust components, the Science of the Total Environment 235 (1999) 65-69

[26] B. Saerens, J. Vandersteen, T. Persoons, J. Swevers, M. Diehl, E. Van den Bulck, Minimization of the fuel consumption of a gasoline engine using dynamic optimization, Applied Energy, Volume 86, Issue 9, September 2009, Pages 1582-1588, ISSN 0306-2619, DOI: 10.1016/j.apenergy.2008.12.022.

[27] Wenzel, T. 2003; Use of Remote Sensing measurements to evaluate vehicle emission monitoring programs: results from Phoenix, Arizona. Environmental Science and Policy Volume 6, Issue 2: pp 153-166.

[28] Wielenmann et al., Regulated and unregulated diesel and cold start emissions at different temperatures, Atmospheric Environment, vol 39 (2005), 2433-2441)

[29] Myung et al. Experimental investigation of the effect of thin- wall substrates and spark timing on total hydrocarbon emissions during cold-start for super-ultra low-emission application, Journal of Automobile Engineering, Vol 218, Part D (2004)

[30] Pang et al., Review of engine cooling technologies for modern engines. Journal of automotive engineering, Vol 218, Part D (2004)

[31] VOSA: Vehicle & Operator Services Agency, 2006; The MOT Inspection Manual; Car and Light Commercial Vehicle Testing, UK Department for Transport, London, UK.

[32] Wenzel, T., Singer, B.C. and Slott, R., 2000; Some issues in the statistical analysis of vehicle emissions. Journal of Transportation Statistics, September 2000. pp 1-14.

[33] Baltusis, P. 2004; On-board vehicle diag nostics. Convergence Transportation Electronics Association, Paper 2004-21-0009

[34] Fuller, G., 2006; London Air Quality 2004; London Air Quality Network Report 12; Environmental Research Group, London, UK.

[35] Harrison, R.M., Tilling, R., Callen Romero, M.S., Harrad, S. and Jarvis, K. 2003; A study of trace metals and polycyclic aromatic hydrocarbons in the roadside environment. Atmospheric Environment 37 (17): pp 2391-2402.

[36] Shi, J.P., Harrison, R.M., Evans, D.E., Alam, A., Barnes, C. and Carter, G. 2002; A method for measuring particle number emissions from vehicles driving on the road. Environmental Technology, Volume 23, Number 1: pp 1-14

[37] Hausberger, S; Rodler, J; Sturm, P; and Rexeis, M. 2003. Emission factors for heavy duty vehicles and validation by tunnel measurements. Atmospheric Environment 37: pp5237-5245.

[38] http://www.environment.nsw.gov.au/air/mvefs.htm, date accessed 4th April 2010.

[39] Bishop, G.A. and Stedman, D.H. 1996; Measuring the emissions of passing cars. Accounts of chemical research, Volume 29, Number 10: pp 489-495.

[40] Jimenez, J.L., Koplow, M.D., Nelson, D.D., Zahniser, M.S. and Schmidt, S.E. 1999; Characterisation of on-road vehicle NO emissions by a TILDAS sensor. Journal of the Air and Waste Management Association 49: pp463-470

[41] Moosmuller, H., Mazzoleni, C., Barber, P.W., Kuhns, H.D., Keislar, R.E. and Watson, J.G. 2003; On-road measurement of automotive particu late emissions by ultraviolet lidar and transmissometer: Instrument. Environmental Science and Technology 37: pp4971-4978.

[42] Bishop, G.A., Stedman, D.H., De La Garza Castro, J., and Davalos, F.J. 1997; On-road remote sensing of vehicle emissions in Mexico; Environmental Science and Technology 31: pp 3505¬3510.

[43] Bradley, K.S., Brooks, K.B., Hubbard, L.K., Popp, P.J. and Stedman, D.H. 2000; Motor-vehicl e fleet emissions by OP-FTIR. Environmental Science and Technology 34: pp 897-899.

[44] Stephens, R.D., Giles, M., McAl inden, K., Gorse, R.A., Hoffman, D. and James, R. 1997; An analysis of Michigan and Califor nia CO remote sensing measurements. Journal of the Air and Waste Management Association 47: pp 601-607.

[45] Pokharel, S.S., Bishop, G.A. and Stedman, D.H. 2002; An on-ro ad motor vehicle emissions inventory for Denver: An efficient alternative to modeling. Atmospheric Environment 36: pp5177¬5184.

[46] Wenzel, T., Singer, B.C. and Slott, R., 2000; Some issues in the statistical analysis of vehicle emissions. Journal of Transportation Statistics, September 2000. pp 1-14.

[47] R.J. North "Assessment of real-world pollutant emissions from a light duty diesel vehicle". PhD Thesis, University of London, 2006. Available online at http://www.cts.cv.ic.ac.uk/documents/theses/NorthPhD.pdf

[48] Sturm, P.J., Kirchweger, G., Hausberger, S. and Almbauer, R.A. 1998; Instantaneous emi ssion data and their use in estimating road traffic emissions. International Journal of Vehicle Design, Volume 20, Numbers 1-4: pp 181-191.

[49] http://www.environment.nsw.gov.au/air/mvefs.htm, date accessed 4th April 2010.

[50] Samuel, S., Austin, L. and Morrey, D. 2002; Automotive test drive cycles for emission measurement and real-world emission levels – a review. Proceedings of the Institute of Mechanical Engineers Volume 216 Part D: Journal of Automobile Engineering, pp555-564

[51] Färnlund, J. and Engström, C. 2001; The representativeness of driving cycles in real-world traffic. Rototest A.B. Publication 2001:35/E, Document ID RP-010122. Rönninge, Sweden

[52] Esteves-Booth, A., Muneer, T., Kirby, H., Kubie, H. and Hunter, J. 2001; The measurement of vehicular driving cycle within the city of Edinburgh. Transportation Research Part D 6: pp 209¬220.

[53] Younglove, T., Scora G. and Barth M. 2005; Designing on-road vehicle test programs for the development of effective vehicle emission models. Transportation Research Record No. 1941, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp 51-59.

[54] De Haan, P. and Keller, M. 2001; Real-world driving cycles for emission measurements: ARTEMIS and Swiss cycles. Report to the Swiss Agency for Environment Forests and Landscape (BUWAL). 17th March 2001.

[55] André, M. 2004; Th e ARTEMIS European drive cycles for measuring car pollutant emissions. Science of the Total Environment Volumes 334-335: pp 73-84.

[56] Rakha, H., and Ahn, K. 2004; Integration modeling framework for estimating mobile source emissions. Journal of Transportation Engineering, Volume 130 (2): pp 183-193.

[57] Ensfield, C. 2002; On-Road emissions testing of 18 Tier 1 passenger cars and 17 diesel-powered public transport buses. Report prepared for the Environmental Protection Agency (EPA), Report number EPA420-R-02-030, October 2002.

[58] Hart, C., Koupal, J., Giannelli, R. 2002: EPA's Onboard Emissions Analysis Shootout: Overview and Results; EPA report EPA420-R-02-026, Assessments and standards division, Office of transportation and air quality, US Environmental Protection Agency

[59] Davis, N., Lents, J, Osses, M., Nikkila, N. and Barth, M. 2005; Development and application of an international vehicle emissions model. Transportation Research Record No. 1939. Transportation Research Board of the National Academy of Sciences, Washington, D.C., pp 157-165.

[60] Kihara, N., Tsukamoto, T., Matsumoto, K., Ishida, K., Kon, M. and Murase, T. 2000; Real-time on-board measurement of mass emission of NOx, fuel consumption, road load and engine output for diesel vehicles. Society of Automotive Engineers Technical Paper 2000-01-114 1.

[61] Frey, H.C., Rouphail, N.M., Unal, A. and Colyar, J.D. 2001; Emissions reduction through better traffic management: An empirical investigation based upon on-road measurements. Report No. FHWT/NC/2002-001 prepared for the North Carolina Department of Transportation.

[62] Ayala, A., Kado, N.Y., Okamoto, R.A., Holmen, B.A., Kuzmicky, P.A., Kobayashi, R. and Stiglitz, K.E. 2002; Diesel and CNG Heavy-duty transit bus emissions over multiple driving schedules: Regulated pollutants and project overview. Society of Automotive Engineers Paper 2002-01¬1722.

[63] Cadle, S.H., Croes, B.E., Minassian, F., Natarajan, M., Tierney, E.J. and Lawson, D.R. 2004; Real-world vehicle emissions: a summary of the thirteenth Coordinating Research Council on-road vehicle em issions workshop. Journal of the Air and Waste Management Association 54: pp8-23.

[64] Cadle, S.H., Gorse, R.A., Bailey, B.K. and Lawson, D.R. 2003; Real-world vehicle emis sions: a summary of the twelfth Coordinating Research Council on-road vehicle emissions workshop. Journal of the Air and Waste Management Association 53: pp152-167.

[65] Holmen, B.A. and Niemeier, D.A. 1998; Characterizing the effects of driver variability on real-world vehicle emissions. Transportation Research D, 3(2), pp.117-128.

[66] Nam, E.K., Gierczak, C., and Butler, J.W. 2003; A comparison of real-world and modeled emissions under conditions of variable aggressiveness. Presented at the 81st Meeting of the Transportation Research Board, Washington DC, 2003.

[67] Daham, B., Andrews, G.E., Li, H., Partridge, M., Bell, M.C. and Tate, J. 2005; Quantifying the effects of traffic calming on emissions using on-road measurements. Society of Automo tive Engineers Technical Paper 2005-05-158.

[68] Unal, A. Frey H.C., and Rouphail, N.M. 2004; Quantification of vehicle emissions hot spots based upon on-board measurements. Journal of the Air and Wa ste Management Association, Volume 54, pp 130-140.

[69] Latham, S., Petley, L.J., Hickman, A.J. and Cloke, J. 2000; A review of available road traffic emission mo dels. TRL report number 457. ISSN 0968-4107.

[70] Düring, I., Bächlin, W., Baum, A., Hausmann, A. and Lohmeyer, A. 2005; Emission Factors for vehicle induced, non-exhaust PM. In proceedings of 14th International Conference on Transport and Air Pollution, Graz, Austria, 2005. pp 382-390.

[71] Ntziachristos, L. and Samaras, Z. 2000; COPERT III: Computer program to calculate emissions from road transport – Methodology and Emissions Factors (Version 2.1). European Environment Agency, Technical Report 49, November 2000.

[72] Edward C., Bright T., Air quality and MOLAND: Description of a methodology to determine emissions output and affected populations, Working Paper Series, May 2008,

[73] http://lat.eng.auth.gr/copert/, date accessed: 5th April 5, 2010.

[74] Ekström, M., Sjödin, Å. and Andreasson, K. 2004; Evaluation of the COPERT III emission model with on-road optical remote sensing measurements. Atmospheric Environment 38: pp 6631-6641.

[75] Pokharel, S.S., Bishop, G.A. and Stedman, D.H. 2002; An on-road motor vehicle emissions inventory for Denver: An efficient alternative to modeling. Atmospheric Environment 36: pp5177¬5184.

[76] Smit,Robin; Smokers,Richard; Rabé,Elke. 2007; A new modelling approach for road traffic emissions: VERSIT+. Transportation Research Part D: Transport and Environment 12, 6, 414-422

[77] J. Andrew Kelly, et. Al, Profiling road transport activity: Emissions from 2000 to 2005 in Ireland using national car test data, Transport Policy, Volume 16, Issue 4, August 2009, Pages 183-192

[78] Arteconi, A., et al., (2010), "Life-cycle greenhouse gas analysis of LNG as a heavy vehicle fuel in Europe", Appl.Energy, Vol.87 (6), pp. 2005-2013.

[79] Han Hao, Hewu Wang, Lingjun Song, Xihao Li, Minggao Ouyang, Energy consumption and GHG emissions of GTL fuel by LCA: Results from eight demonstration transit buses in Beijing, Applied Energy, Volume 87, Issue 10, October 2010, Pages 3212-3217, ISSN 0306-2619, DOI: 10.1016/j.apenergy.2010.03.029

[80] Jose M Lopez, Alvaro Gomez, Francisco Aparicio, Fco. Javier Sanchez, Comparison of GHG emissions from diesel, biodiesel and natural gas refuse trucks of the City of Madrid, Applied Energy, Volume 86, Issue 5, May 2009, Pages 610-615, ISSN 0306-2619, DOI: 10.1016/j.apenergy.2008.08.018.

[81] Lindfeldt, E.G., et al., (2010), "Strategies for a road transport system based on renewable resources – The case of an import-independent Sweden in 2025", Appl.Energy, Vol.87 (6), pp. 1836-1845.

[82] Y. Saboohi, H. Farzaneh, Model for developing an eco-driving strategy of a passenger vehicle based on the least fuel consumption, Applied Energy, Volume 86, Issue 10, October 2009, Pages 1925-1932, ISSN 0306-2619, DOI: 10.1016/j.apenergy.2008.12.017.)

[83] Brian Vad Mathiesen, Henrik Lund, Kenneth Karlsson, 100% Renewable energy systems, climate mitigation and economic growth, Applied Energy, In Press, Corrected Proof, Available online 31 March 2010, ISSN 0306-2619, DOI: 10.1016/j.apenergy.2010.03.001.

[84] Smit, R., et al., (2010), "Validation of road vehicle and traffic emission models - A review and meta-analysis", Atmos.Environ, Vol.44 (25), pp. 2943-2953.

[85] R.J. North "Assessment of real-world pollutant emissions from a light duty diesel vehicle". PhD Thesis, University of London, 2006. Available online at http://www.cts.cv.ic.ac.uk/documents/theses/NorthPhD.pdf

[86] André, M., et al., (2006), "Real-world European driving cycles, for measuring pollutant emissions from high- and low-powered cars", Atmos.Environ., Vol.40 (31), pp. 5944-5953.

[87] André, M. 2004; Th e ARTEMIS European drive cycles for measuring car pollutant emissions. Science of the Total Environment Volumes 334-335: pp 73-84.

[88] Tzirakis, E., et al., (2006), "Vehicle emissions and driving cycles: comparison of the Athens driving cycle (ADC) with ECE-15 and European driving cycle (EDC)", Global NEST Journal, Vol.8 (3), pp. 282–290.

[89] Hung, W., et al., (2007), "Development of a practical driving cycle construction methodology: A case study in Hong Kong", Transportation Research Part D, Vol.12 (2), pp. 115-128.

[90] Alessandrini A, Filippi F, Orecchini F, et al., A new method for collecting vehicle behaviour in daily use for energy and environmental analysis, Proceedings of the Institution of Mechanical Engineers Part D – Journal of Automobile Engineering 220 (D 11): 1527-1537 (Nov 2006)

[91] DeHaan P, and KellerM., Emission factors for passenger cars and light duty vehicles, Handbook of emissions factors (hbefa), Technical Report, Version 2.1, SAEFL, UBA Bern/UBA Berlin/UBA Viennaa, 2004

[92] Society of Automotive Engineers International, SAE j1979,E/E Diagnostic Test Modes, 2002

[93] Toyota Motor Sales, USA, Overview of OBD Regulations, http://www.autoshop101.com/forms/h46.pdf

[94] Declan Deery, DD, 2007, Estimation of On-Road Vehicle Fuel Consumption and Emissions using Analysis of On-Board Diagnostic signals, Bachelor of Engineering, University College Dublin.

[95] Alessandrini A, Filippi F, Orecchini F, et al., A new method for collecting vehicle behaviour in daily use for energy and environmental analysis, Proceedings of the Institution of Mechanical Engineers Part D – Journal of Automobile Engineering 220 (D 11): 1527-1537 (Nov 2006).

[96] Giannouli, M., et al., "Impact of European emission control strategies on urban and local air quality", Atmos.Environ., Vol.In Press, Accepted Manuscript .

[97] Pouliot, G., et al., "Comparing emission inventories and model-ready emission datasets between Europe and North America for the AQMEII project", Atmos.Environ., (0),.

[98] Sharad, G. (2012), "Impacts of traffic-flows on vehicular-exhaust emissions at traffic junctions", Transportation Research Part D: Transport and Environment, Vol.17 (1), pp. 21-27.

[99] Rabl, A.and de Nazelle, A., (2012), "Benefits of shift from car to active transport", Transp.Policy, Vol.19 (1), pp. 121-131.

[100] Su, J., et al., (2011), "Non-methane volatile organic compound emission inventories in Beijing during Olympic Games 2008", Atmos.Environ., Vol.45 (39), pp. 7046-7052.

[101] Wang, H., et al., (2010), "Trends in vehicular emissions in China's mega cities from 1995 to 2005", Environmental Pollution, Vol.158 (2), pp. 394-400.

[102] Ntziachristos, L., Samaras, Z., 2000a. COPERT III Computer Programme to Calculate Emissions from Road Transport, Methodology and Emission Factors (Version 2.1). European Environmental Agency ETC/AEM Technical Report 49.

[103] Ntziachristos, L.and Samaras, Z., (2000), "Speed-dependent representative emission factors for catalyst passenger cars and influencing parameters", Atmos.Environ., Vol.34 (27), pp. 4611-4619.

[104] Haydar, F. and Pediaditi, K. 2010. Evaluation of the environmental impact assessment system in Syria. Environmental Impact Assessment Review, 30(6), pp.363-370.

[105] Ou, X., Yan, X., Zhang, X. and Liu, Z. 2012. Life-cycle analysis on energy consumption and GHG emission intensities of alternative vehicle fuels in China. Applied Energy, 90(1), pp.218-224.

[106] Ayoub, K. 2003. Introduction of PEM fuel-cell vehicles in the transportation sector of the United Arab Emirates. Applied Energy, 74(1-2), pp.125-133.

[107] Hussam Achour and Abdul Ghani Olabi, Estimating on-road emissions using a special driving cycle for Dublin, International Conference on Simulation Based Engineering and Sciences (TCN CAE 2008),16th - 17th October 2008, Venice, Italy.

[108] Hussam Achour and Abdul Ghani Olabi, Comparison between measured and estimated vehicle emissions from road transport. Proceeding of the 3rd International Conference on Sustainable Energy & Environmental Protection Part 1, p24-29, 12th -15th August 2009, Dublin, Ireland.

[109] Hussam Achour, James Carton and Abdul Ghani Olabi, Estimating Vehicle Emission from Road Transport, case study: Dublin City. Applied Energy, Volume 88, Issue 5, May 2011, Pages 1957-1964

[110] Hussam Achour and Abdul Ghani Olabi and Abdullah Marashly, Development of a practical driving cycle for simulation of car emissions: a case study in Aleppo city, Syria, 5th Dubrovnik Conference on Sustainable Development of Energy Water and Environment Systems (SDEWES2009), September 29 - October 3 2009, Dubrovnik, Croatia.

[111] Hussam Achour, Abdullah Marashly, and Abdul Ghani Olabi, Assessing Energy Consumption of the Transport Sector in Aleppo, SYRIA, Applied Energy. Paper is under revision.

Appendices

Appendix A

SAE j1979, OBD PIDs and Scaling Factors

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	00	4	PIDs supported				Bit encoded [A7..D0] == [PID 0x01..PID 0x20]
01	01	4	Number of trouble codes and I/M info				Bit encoded. See below.
01	03	2	Fuel system status				Bit encoded. See below.
01	04	1	Calculated engine load value	0	100	%	A*100/255
01	05	1	Engine coolant temperature	-40	215	°C	A-40
01	06	1	Short term fuel % trim—Bank 1	-100 (lean)	99.22 (rich)	%	0.7812 * (A-128)
01	07	1	Long term fuel % trim—Bank 1	-100 (lean)	99.22 (rich)	%	0.7812 * (A-128)
01	08	1	Short term fuel % trim—Bank 2	-100 (lean)	99.22 (rich)	%	0.7812 * (A-128)
01	09	1	Long term fuel % trim—Bank 2	-100 (lean)	99.22 (rich)	%	0.7812 * (A-128)
01	0A	1	Fuel pressure	0	765	kPa (gauge)	A*3
01	0B	1	Intake manifold pressure	0	255	kPa (absolute)	A
01	0C	2	Engine RPM	0	16,383.75	rpm	((A*256)+B)/4
01	0D	1	Vehicle speed	0	255	km/h	A
01	0E	1	Timing advance	-64	63.5	° relative to #1 cylinder	A/2 - 64
01	0F	1	Intake air temperature	-40	215	°C	A-40
01	10	2	MAF air flow rate	0	655.35	g/s	((256*A)+B) / 100
01	11	1	Throttle position	0	100	%	A*100/255
01	12	1	Sec.(?) air status				Bit encoded. See below.
01	13	1	Oxygen sensors present				[A0..A3] == Bank 1, Sensors 1-4. [A4..A7] == Bank 2...

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	14	2	Bank 1, Sensor 1: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	15	2	Bank 1, Sensor 2: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	16	2	Bank 1, Sensor 3: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	17	2	Bank 1, Sensor 4: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	18	2	Bank 2, Sensor 1: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	19	2	Bank 2, Sensor 2: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	1A	2	Bank 2, Sensor 3: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	1B	2	Bank 2, Sensor 4: Oxygen sensor voltage, Short term fuel trim	0 0	1.275 99.2	Volts %	A * 0.005 (B-128) * 0.7812 (if B==0xFF, sensor is not used in trim calc)
01	1C	1	OBD standards this vehicle conforms to				Bit encoded. See below.
01	1D	1	Oxygen sensors present				Similar to PID 13, but [A0..A7] == [B1S1, B1S2, B2S1, B2S2, B3S1, B3S2, B4S1, B4S2]

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	1E	1	Auxiliary input status				A0 == Power Take Off (PTO) status (1 == active) [A1..A7] not used
01	1F	2	Run time since engine start	0	65,535	seconds	(A*256)+B
01	20	4	PIDs supported 21-40				Bit encoded [A7..D0] == [PID 0x21..PID 0x40]
01	21	2	Distance traveled with malfunction indicator lamp (MIL) on	0	65,535	km	(A*256)+B
01	22	2	Fuel Rail Pressure (relative to manifold vacuum)	0	5177.265	kPa	((A*256)+B) * 0.079
01	23	2	Fuel Rail Pressure (diesel)	0	655350	kPa (gauge)	((A*256)+B) * 10
01	24	4	O2S1_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	25	4	O2S2_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	26	4	O2S3_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	27	4	O2S4_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	28	4	O2S5_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	29	4	O2S6_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	2A	4	O2S7_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	2B	4	O2S8_WR_lambda(1): Equivalence Ratio Voltage	0 0	2 8	N/A V	((A*256)+B)*0.0000305 ((C*256)+D)*0.000122
01	2C	1	Commanded EGR	0	100	%	100*A/255
01	2D	1	EGR Error	-100	99.22	%	A*0.78125 – 100
01	2E	1	Commanded evaporative purge	0	100	%	100*A/255
01	2F	1	Fuel Level Input	0	100	%	100*A/255
01	30	1	# of warm-ups since codes cleared	0	255	N/A	A
01	31	2	Distance travelled since codes cleared	0	65,535	km	(A*256)+B
01	32	2	Evap. System Vapor Pressure	-8,192	8,192	Pa	((A*256)+B)/4 - 8,192
01	33	1	Barometric pressure	0	255	kPa (Absolute)	A
01	34	4	O2S1_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	35	4	O2S2_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	36	4	O2S3_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	37	4	O2S4_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	38	4	O2S5_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	39	4	O2S6_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	3A	4	O2S7_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	3B	4	O2S8_WR_lambda(1): Equivalence Ratio Current	0 -128	2 128	N/A mA	((A*256)+B)*0.0000305 ((C*256)+D)*0.00391 – 128
01	3C	2	Catalyst Temperature Bank 1, Sensor 1	-40	6,513.5	°C	((A*256)+B)/10 -40
01	3D	2	Catalyst Temperature Bank 1, Sensor 2	-40	6,513.5	°C	((A*256)+B)/10 -40
01	3E	2	Catalyst Temperature Bank 2, Sensor 1	-40	6,513.5	°C	((A*256)+B)/10 -40
01	3F	2	Catalyst Temperature Bank 2, Sensor 2	-40	6,513.5	°C	((A*256)+B)/10 -40
01	40	4	PIDs supported 41-60 (?)				Bit encoded [A7..D0] == [PID 0x41..PID 0x60] (?)
01	41	?	Monitor status this drive cycle	?	?	?	?
01	42	2	Control module voltage	0	65.535	V	((A*256)+B)/1000
01	43	2	Absolute load value	0	25696	%	((A*256)+B)*100/255
01	44	2	Command equivalence ratio	0	2	N/A	((A*256)+B)*0.0000305
01	45	1	Relative throttle position	0	100	%	A*100/255
01	46	1	Ambient air temperature	-40	215	°C	A-40

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula
01	47	1	Absolute throttle position B	0	100	%	A*100/255
01	48	1	Absolute throttle position C	0	100	%	A*100/255
01	49	1	Accelerator pedal position D	0	100	%	A*100/255
01	4A	1	Accelerator pedal position E	0	100	%	A*100/255
01	4B	1	Accelerator pedal position F	0	100	%	A*100/255
01	4C	1	Commanded throttle actuator	0	100	%	A*100/255
01	4D	2	Time run with MIL on	0	65,535	minutes	(A*256)+B
01	4E	2	Time since trouble codes cleared	0	65,535	minutes	(A*256)+B
01	C3	?	?	?	?	?	Returns numerous data, including Drive Condition ID and Engine Speed*
01	C4	?	?	?	?	?	B5 is Engine Idle Request B6 is Engine Stop Request*
02	02	2	Freeze frame trouble code				BCD encoded, see below.
03	N/A	n*6	Request trouble codes				3 codes per message frame, BCD encoded. See below.
04	N/A	0	Clear trouble codes / Malfunction indicator lamp (MIL) / Check engine light				Clears all stored trouble codes and turns the MIL off.
09	02	5x5	Vehicle identification number (VIN)				Returns 5 lines, A is line ordering flag, B-E ASCII coded VIN digits.

Appendix B

COPERT software displays

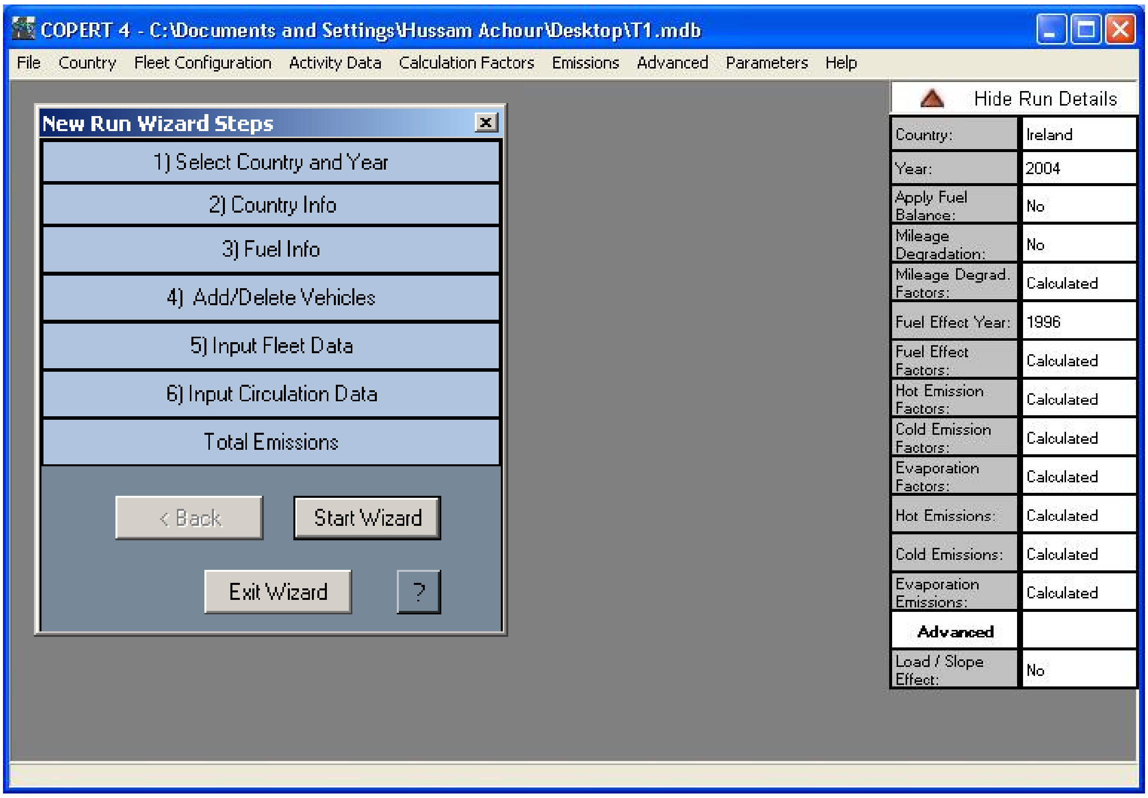


Figure 1: Fistly, parametres have to be filed in order to run a new wizard setup

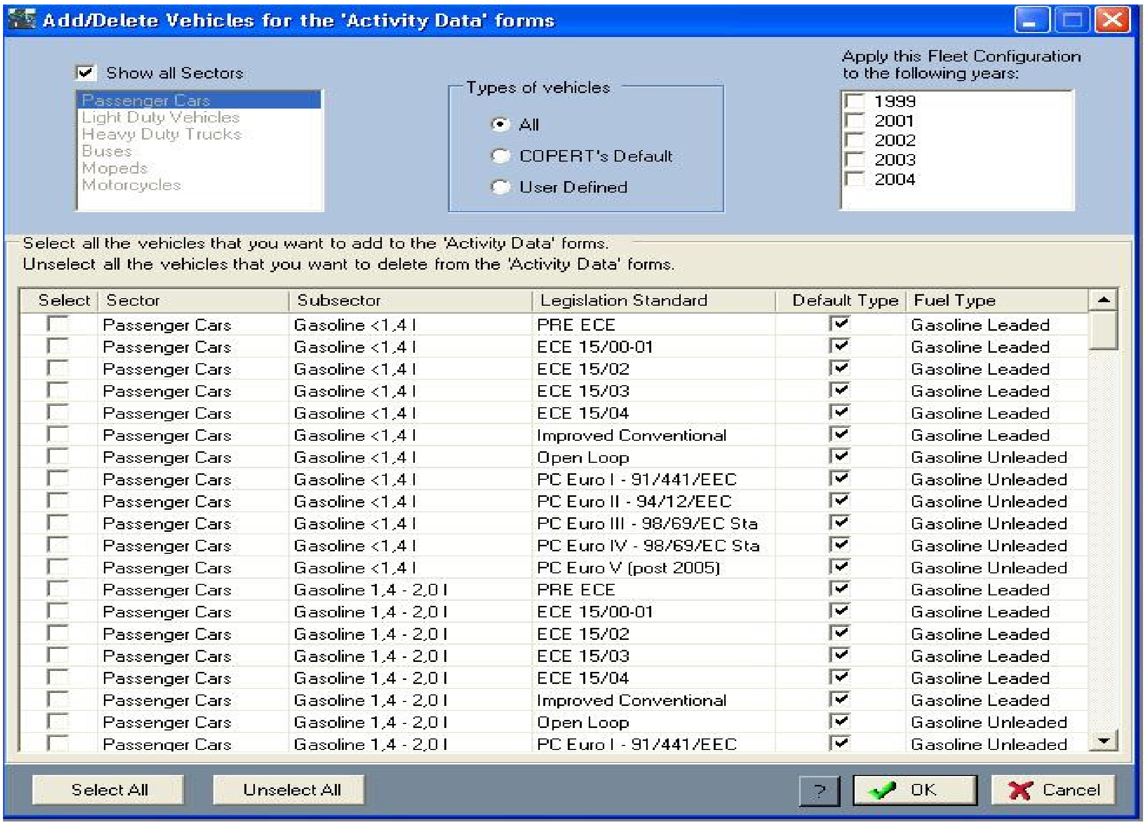


Figure 2: National data has to be filled for each sector, subsector and ligislation standard.

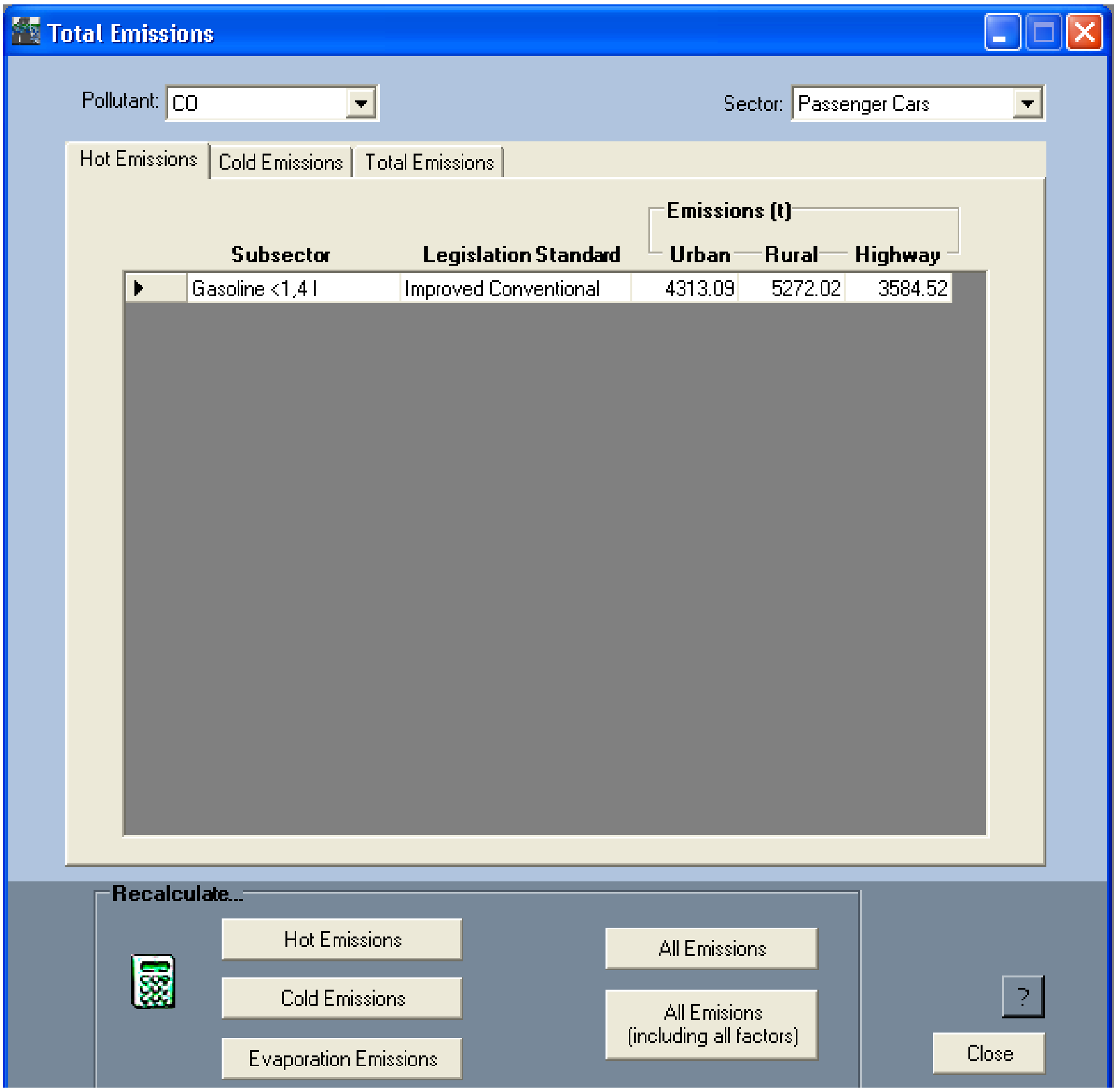


Figure 4: Hot, Cold and Evaporative emisions are calculated in this part

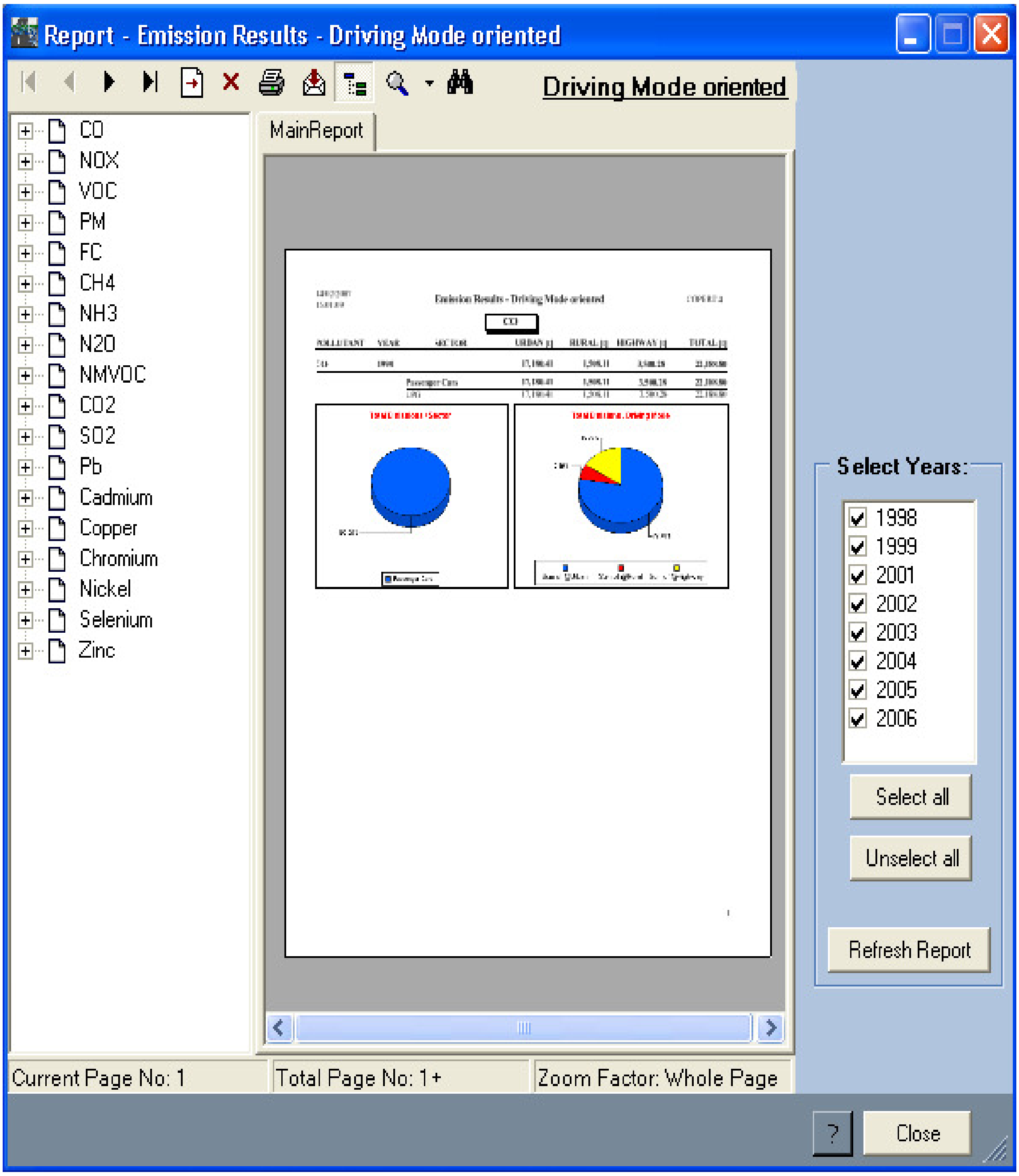


Figure 5: Data plotted as driving mode oriented.

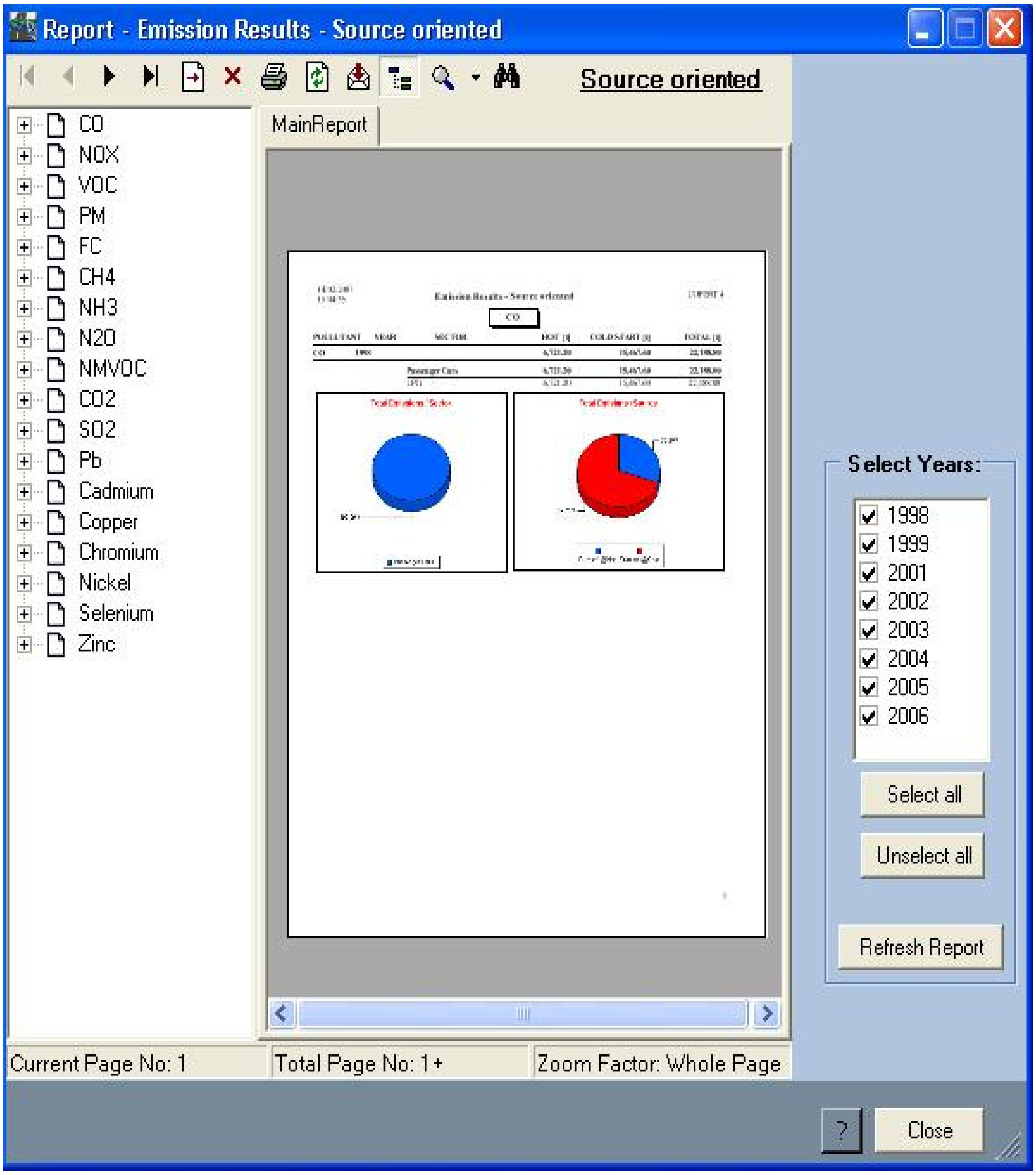


Figure 5: Data plotted as sorce oriented.

Appendix C

Emissions and Vehicle Usage Graphs

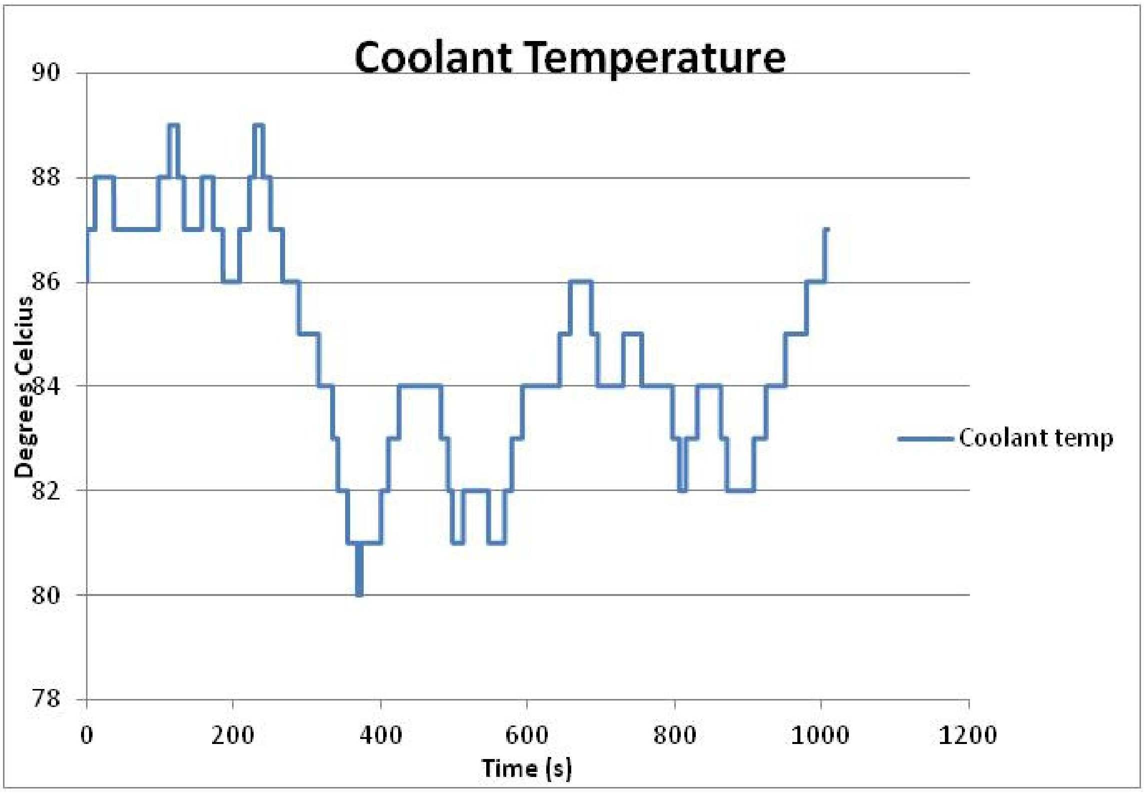


Figure 1: Coolant Temperature during Estimated Emissions Testing

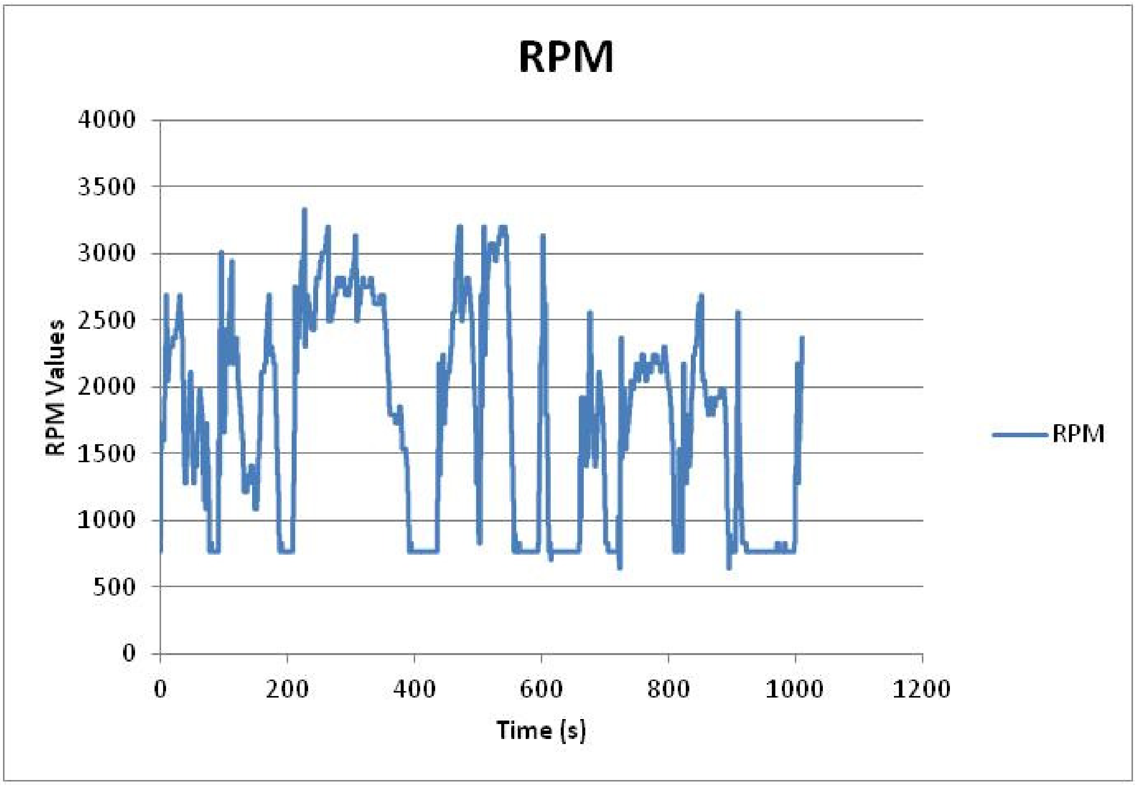
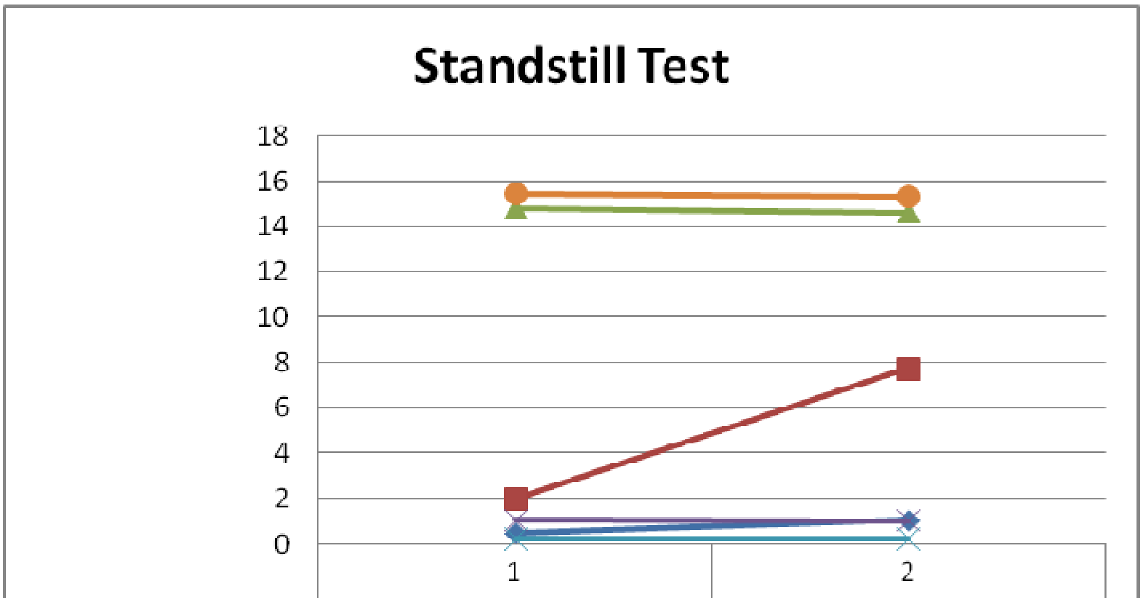


Figure 2: RPM of Engine during Estimated Emissions Testing



	1	2
HC	0.49	1.06
CO	2.003	7.749
CO2	14.81	14.63
Lambda	1.05	1.04
NOx	0.23	0.23
Air/Fuel Ratio	15.43	15.29

Figure 3: Review of Standstill Testing Start to Finish

Short Urban Cycle

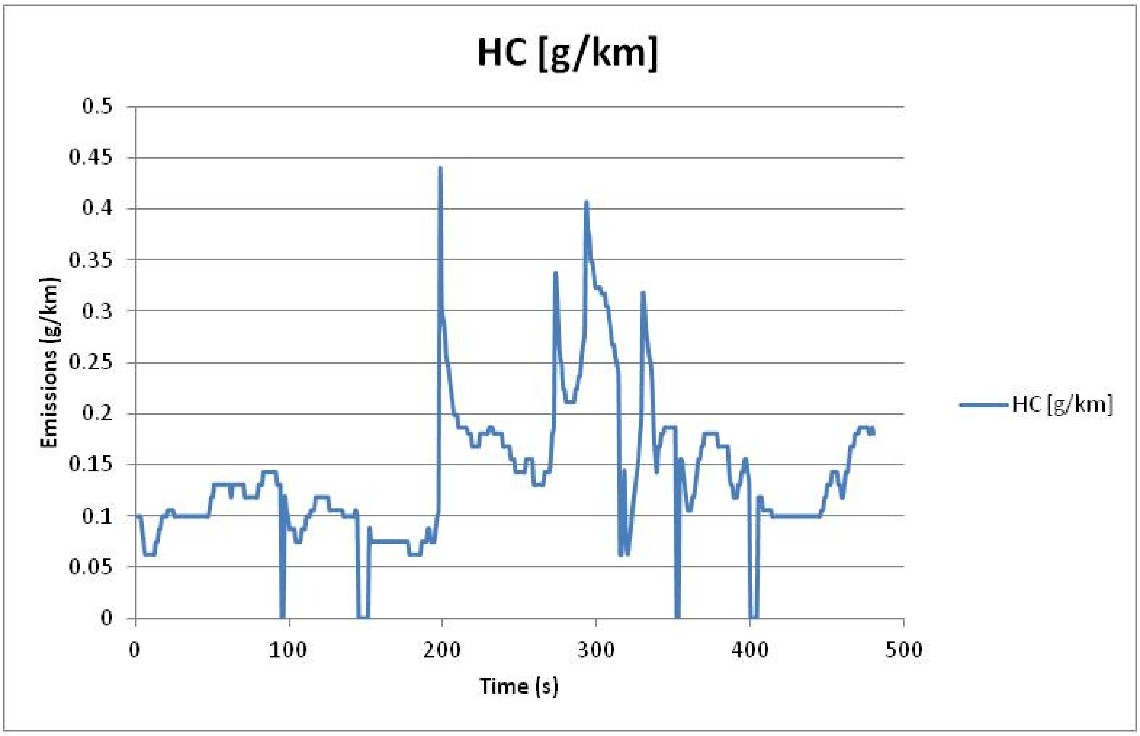


Figure 4: Emission of HC

Vol% vs. Time

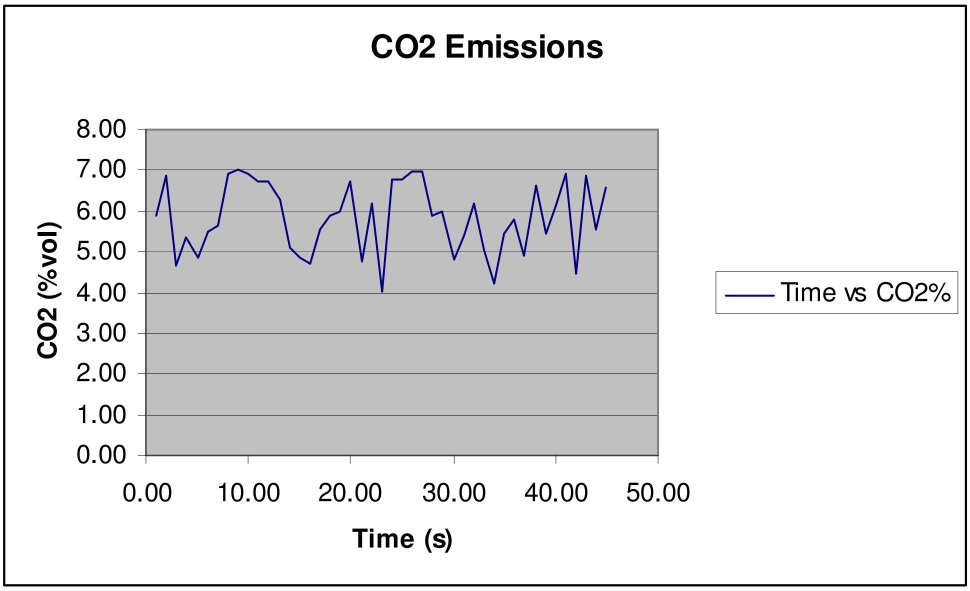


Figure 5: CO2 Emissions graph

G/s vs. Time

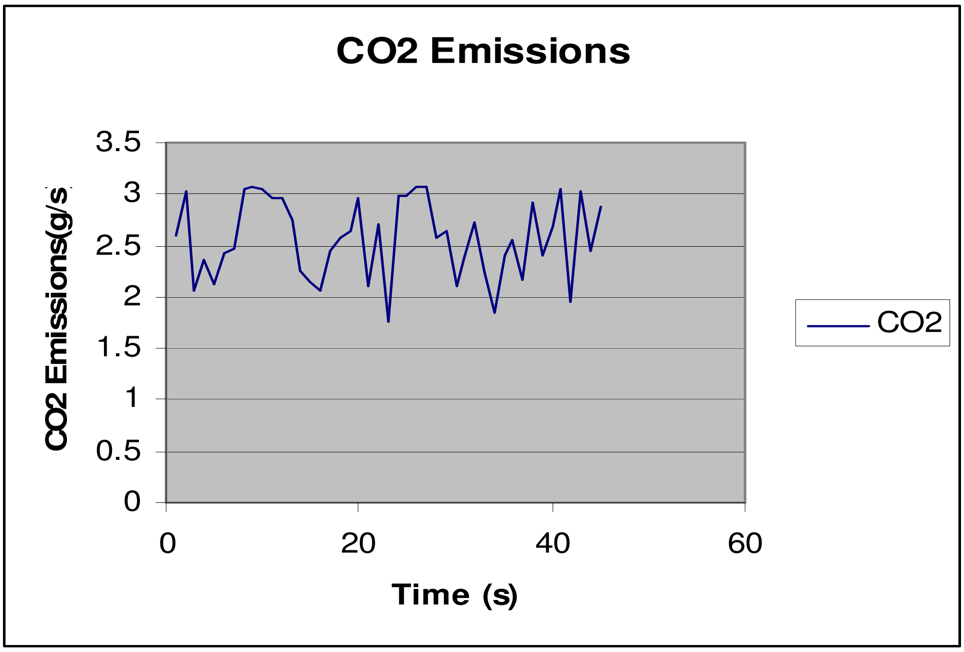


Figure 6: CO2 Emissions graph

Vol% vs. Time

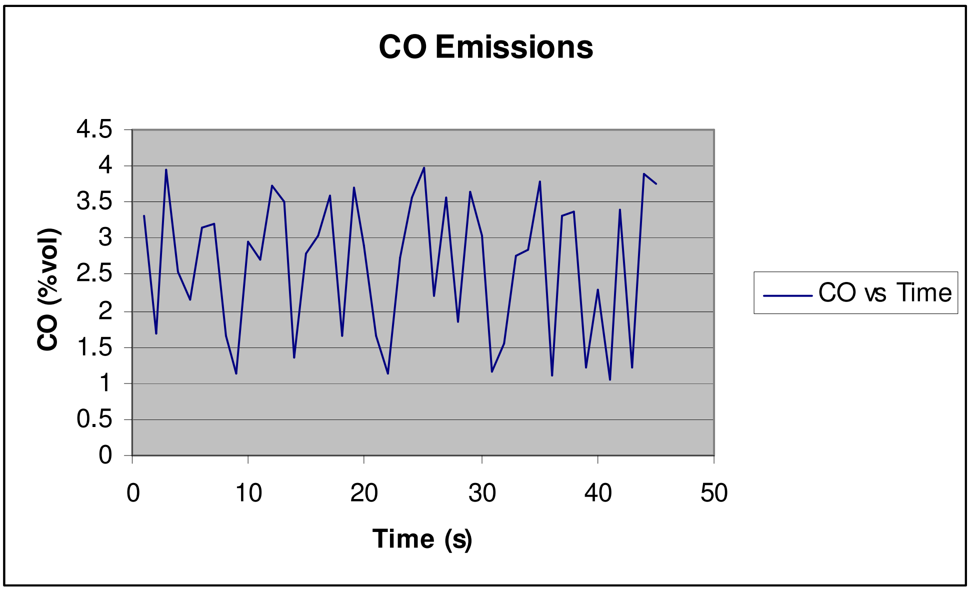


Figure 7: CO Emissions graph

G/s vs. Time

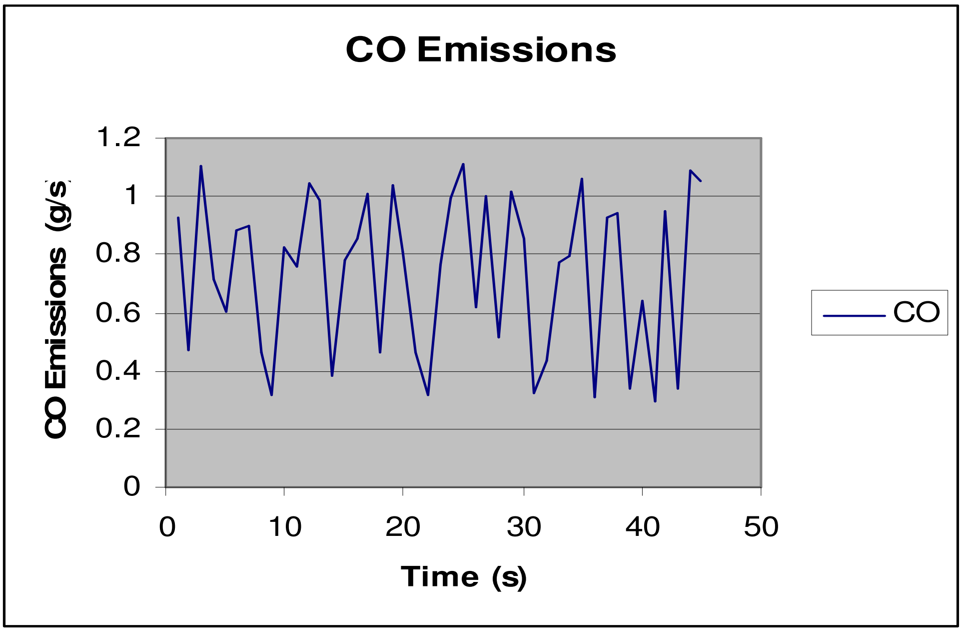


Figure 8: CO Emission graph

PPM vs. Time

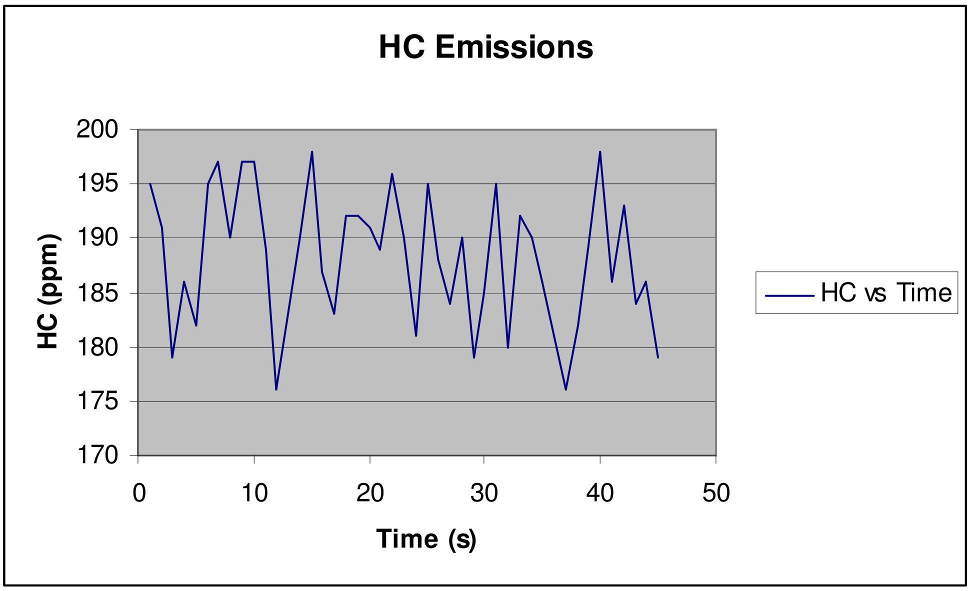


Figure 9: HC Emissions graph

PPM vs. Time

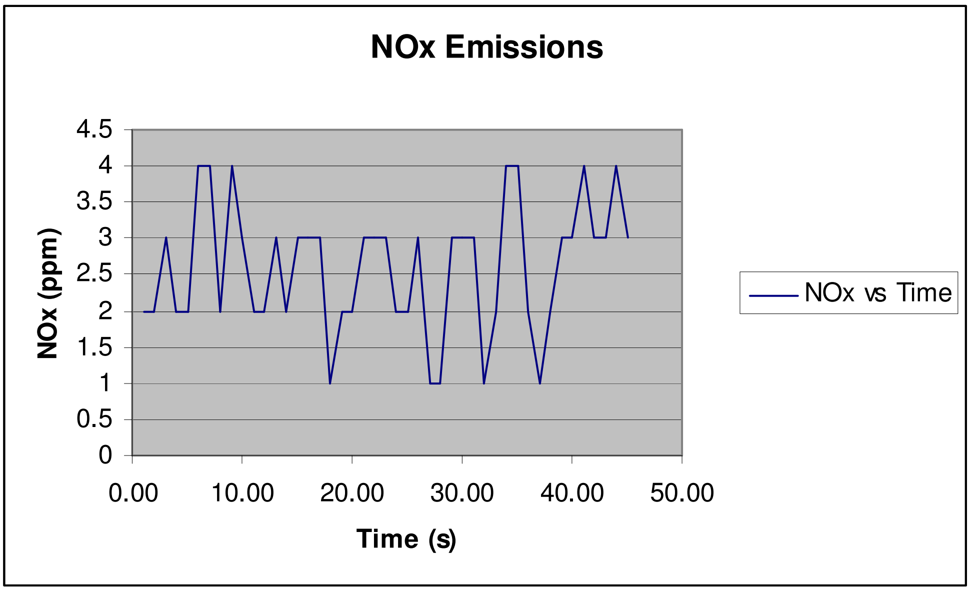


Figure 10: CO2 Emissions graph