Investigation of Driving Cycles as Tools to Assess Travel Demand Management in Edinburgh and Abu Dhabi

By

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Abstract

Traffic congestion today is a major problem in almost all of the metropolitan areas of the world. An increasing level of congestion results in negative impacts on the urban environment. These include environmental pollution, energy problems and traffic accidents. The analysis of these problems and the predictions of the impacts of any transport policies that could be devised to deal with them are very critical to their success. Traffic problems are almost the same in most modern cities either in developed countries or less economically developed countries.

The driving cycle for a vehicle is the representation of a speed–time sequenced profile, which is developed for a specific area or city. It is an important requirement in the evaluation of the driver's behaviour and the performance of vehicles for a number of applications, mainly in the area of environmental studies. For example, fuel consumption and emissions' predictions need information input on the characteristics of driving patterns of traffic. The applications of driving cycle analysis can be extended however, to many more other areas. The motivation for this research is to investigate the detailed impacts of travel demand management (TDM) measures, that are already in application. This is to improve the network performance, using driving cycle analysis. It is important to explicitly assess these measures using a micro-level detailed approach in order to comprehend overall results in terms of emissions and network performance. These understandings will benefit government agencies and policy makers in their planning and appraisals. It will also benefit public transport providers to improve their service in attracting and retaining their customers.

The developments of the real world driving cycles in Edinburgh and Abu Dhabi have been presented in this research. The analysis of real world data, which has been obtained from monitoring traffic conditions in both cities using the GPS tracking of traffic, is presented. This data was collected from trips which have been carried out on a number of traffic corridors in both cities. The assessment of various parameters of traffic (i.e. speed, time percentage spent on acceleration, deceleration, idling, cruising and cycle duration) and their statistical validity, produced a real world driving cycle for the buses as well as the private cars. Two TDM measures have been considered;

bus lanes and traffic calming measures. At each corridor, a handheld GPS device was used to record speed, acceleration, deceleration and distances driven. This data enabled the analysis of driving cycles for the buses and for the private cars. The driving cycle analysis and investigations have further been investigated using regression analysis techniques. The results suggest that the approach shows potential but further research is needed with more data available.

The results suggest that the driving cycle analysis approach would be very useful to have a better understanding of driving behaviour and also the detailed impacts of the transport policies on traffic. In terms of bus lanes and traffic calming measures, the results show some positive impacts of these policies, while there are evidences of some negative impacts as well. These findings would be very valuable for the policy decision makers. It is recommended from this research that the driving cycle analysis could be utilised effectively in the assessment of TDM measures. Further investigations and analysis of driving cycle is urgently recommended in a number of research directions. Combined GIS and GPS data could also enhance the development in this research.

Declaration

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

(Ahmed Al Zaidi)

Signature..

Date ....

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Traffic congestion nowadays is a major problem in almost all of the metropolitan areas of the world. Increasing levels of congestion result in worst predicaments like urban environmental pollution, energy problems and traffic accidents. The situation is the same in most modern cities either in developed countries or Less Economically Developed Countries (LEDC). Urban centres of many LEDCs are experiencing severe congestion and pollution problems. It has been observed that road vehicles are a major source of air pollution in urban areas, responsible for over half the nitrogen dioxide emissions and over 75% of carbon monoxide in the UK (Defra, 2008). In the past, a consensus existed among the transport policymakers that their goal was to accommodate the growing traffic by constructing/improving facilities that would have adequate capacity to handle future demand (Wachs, 1991). Nevertheless increasing congestion coupled with growing limits of transportation budgets and environment halted this strategy. In the late eighties, a growing movement towards Transportation Demand Management (TDM) rather than facility construction gained momentum. TDM represents measures that aim at reducing car dependency and the techniques or supporting strategies that encourage the use of other alternative modes of transport such as public transport, cycling and walking. In other words, TDM measures are aimed at influencing mode choice, trip length, the frequency of trips and the route taken. They can be applied to meeting specific goals, namely to reduce congestion, reduced parking stalls, decrease property owner/manager maintenance costs on parking areas, create more commuting choices for the public, delay the need for new road construction, and to improve air quality or to reduce the reliance on specific source of energy. However, environmental impacts of such measures have not always been considered as the most important consequence; instead the main objective has mainly been traffic performance, congestion and travel time savings. Literature is lacking for comprehensive studies in which environmental impacts of such TDM measures have been carried out to see their overall effect on the metropolis as a whole. Moreover, when conventionally used, these measures are usually assessed using various modelling and analysis techniques (for example travel demand forecasting, simulation modelling etc.), a major limitation of much of these measures is that assessments have been calculated using the conventional criteria such average speed patterns and delays rather than for example real-world driving conditions. Therefore, they do not embrace actual driving behaviour in any particular urban area. Hence in this study, the driving cycle analysis has been utilised to obtain more real data to assess impacts of TDM measures on congestion, delays and travel time in Edinburgh and Abu Dhabi cities. Measurement of instantaneous speed, acceleration, deceleration, and distance travelled and route tracking data were undertaken to develop the driving cycle for each of the modes.

A driving cycle for a vehicle is a representation of a speed–time sequenced profile developed for a specific area or city. It represents the speed of a vehicle versus time. In this way, driving cycles are produced for cities and regions in order to assess the performance of vehicles in various ways, for example fuel consumption and polluting emissions. In most cases they are widely used to estimate transport air pollutant emissions and in the building of databases for emission inventories. The driving cycles for private cars and light goods vehicle (LGV) are important to enhance traffic management systems, determining fuel consumption patterns and reduce transport impacts on health (Tzirakis et al., 2006; Saleh 2007; Hung et al., 2007). There are other potential applications for the driving cycle such as the use of assessing impacts of travel demand management (TDM) in urban areas. In this study the tracking of instantaneous speed of vehicles is used to assess the performance of traffic when implementing TDM measures.

It is important to understand the factors which affect driving cycles in urban and rural areas. Speed is a critical element in the transportation systems. Planning, design, construction and maintenance of roads, traffic engineering and management affect speed. The speed has a critical impact on the capacity, safety, efficiency and the level of service of any road network. Driving cycle's characteristics in urban or rural areas change even for small variations in speed. Traffic and roadside characteristics, vehicular volume and number of intersections in a link, commercial land uses and pedestrian facilities and carriageway width have important effects on speed. Speed of vehicles depends on a number of factors. These factors can be defined as four categories: firstly there are traffic characteristics such as the traffic density, flow, vehicle composition and the type of traffic management. Traffic management measures include speed limits, traffic lights, speed breaker, stop sign (Galin, 1981; Aerde and Yagar, 1983; Polus et al., 1984). The second category is driver characteristics. Driver characteristics are classified as physical, mental, psychological and environmental (Holmen and Niemeier 1997; Ericsson, 2000). The third category is roadside characteristics such as land uses abutting the road network, incidence of on street parking, bus stops and pedestrian facilities (Galin 1981; Aerde and Yagar, 1983; Tignor and Warren, 1990; Poe et al., 1996; Koshy and Thamiz Aharasan, 2005). The fourth category is vehicle characteristics such as model, age of the vehicle, size of the vehicle, power and quality of maintenance. The weather conditions (temperature, visibility, humidity and wind speed) may also have an impact on speed (Liang et al., 1998; Kilpelaninen and Summala, 2004).

Neither previous research nor investigations of driving cycle have been taken place in the city of Abu Dhabi in United Arab Emirates (UAE). As any fast growing city, Abu Dhabi needs to have in place a number of traffic and transport policies in order to regulate and control the growing traffic congestion. Moreover, with the increasing attention and all activities in Abu Dhabi city, there is a greater need for management of traffic and the environment. Driving cycle is an appropriate tool to be used in these cases. This will enable the accurate assessment of the traffic demand in the city, and keeping up with the different international standards and campaigns on the reduction of vehicle emissions for a better environment.

1.2 Statement of the problem

The sustainability of transportation system in respect to the comprehensive approach can be achieved by rendering different strategies to manage and optimally distribute the travel volumes in the urban network. The developed traffic management strategies were implemented at macro level, e.g. in land use planning processes, and also at micro level, e.g. at signalized intersections, but these strategies resolved the problem in an environment where the travel demand was within the capacity/supply level of the provided transportation infrastructure. Once the demand became more than supply, the system again faced congestion and sustainability problems. Moreover, the environmental impacts of such technologies were rather ignored or were not considered at all and the main focus remained on the network performance.

The above addressed problems prompted the emphasis on assessment of applied TDM in order to improve the efficiency and capacity of the system while not compromising the environmental impacts of the applied scheme. Environmental degradation and emissions are the main hurdles in the achievement of sustainability through any TDM technique. However, with proper environmental assessment of the any management scheme under consideration, sustainability can be achieved by keeping emissions low and distributing demand on various alternatives. This means that the analysis of any TDM approach is necessary. Since alternate type of management schemes produce different results, it is important to study the effects before it is actually installed or deployed. Managing the demand for traffic in any urban area is vital. While various transport policies can be investigated and considered as means to manage the demand, in most cases the predicted impacts of such policies are usually considered based on their impacts on delays, travel time and congestion while their environmental impacts are investigated separately. This is the case in most modern cities, either in developed or developing countries. On the other hand, technological advancement in data collection methods and equipment made it possible to collect traffic data second by second on any traffic corridor, for any type of vehicle and for all types of drivers. Therefore driving cycle characteristics can be investigated and modelled much more easily than it was in the past.

Previous studies have been carried out to investigate the driving cycle in Edinburgh (EDC) for cars (Booth et al., 2002). However, its linkage with the assessment of any TDM measure has not been carried out comprehensively. Very few studies actually focused on the assessment of TDM measures together with its environmental effects simultaneously in one behavioural network. But these studies only focused on the average values of attributes of the alternative modes. This study aimed to develop an air quality forecast tool for predicting both the future level of vehicular emission within Edinburgh and measure the effect of different levels of traffic control scenarios. Investigations of driving cycles as a means to assess traffic and environmental impacts of TDM measures have started only recently in the UK and other developed countries, while hasn't happened yet in many developing countries.

The city of Abu Dhabi (UAE) is very typical of any expanding metropolis in the region with huge traffic problems of congestion, delays and pollution. Most of these cities are searching for the appropriate policies and strategies in order to help managing such problems. It is very appropriate therefore to carryout investigations employing driving cycle analysis.

While significant improvements have been achieved in reducing fuel consumption and pollution in Europe following a number of programmes and initiatives (for example the "Act on CO2" and the EU emissions tests from 1997 to 2007), the situation is very different in most developing countries. It is therefore timely to consider such similar studies to be undertaken to investigate these problems in developing countries, in this case the city of Abu Dhabi.

The motivation behind this research is to investigate effects of different TDM measures that are already applied to improve the network performance. It is important to explicitly assess these measures using a micro-level detailed approach in order to comprehend overall results in terms of emissions and network performance. These understandings will benefit government agencies and policy makers in their planning and appraisals. It will also benefit public transport providers to improve their service in attracting and retaining their customers.

1.3 Justification of research

Travel demand management measures have been used to manage the demand for travel for more than three decades or so, mainly in the Western World. The main objectives have been essentially used to reduce negative impacts of traffic and congestion. Improving environmental impacts, accidents reduction as well as impacts of other externalities have always been mentioned as by products of achieving congestion reduction. On the other hand, driving cycle techniques and analysis have been used mainly to predict and model traffic emissions for cars as well as other modes of travel. Driving cycle analysis can be used as a very useful tool to assess impacts of transport policies on environmental and other external issues.

The main aim of this research therefore, is to investigate the potential application of the driving cycle techniques to assess transport policies and the detailed impacts on the built environment in Edinburgh and in Abu Dhabi. In order to achieve this aim a number of objectives have been defined as discussed below.

Bus lanes have been claimed to improve traffic performance, improve bus reliability and reduce delays. However, these claims have been mainly based on findings from studies which investigated the overall bus journey times while not taking into consideration the detailed performance of vehicles along the traffic corridors.

The first objective of this research therefore, is to investigate and analyse the more detailed impacts of bus lanes on traffic using the analysis of the driving cycles of buses on a number of corridors.

In order to achieve that, the driving cycle of a number of traffic corridors with bus lanes, mixed traffic and bus only lanes in Edinburgh have been developed and analysed. In order to assess the detailed impacts of bus lanes on traffic, the driving cycle of the selected three traffic corridors in Edinburgh have been identified and data has been collected using GPS equipment to carry out the investigations. The results obtained are presented in chapter five. Secondly, the developed driving cycles are discussed in chapter six.

In order to assess the performance of traffic over traffic calming corridors, which are claimed to be improving the impacts of traffic, the performance of traffic on a number of traffic calming corridors have been monitored, investigated and analysed. The descriptions of the traffic calming corridors are presented in chapter three. The developments of driving cycles of these corridors are discussed in chapter six and the comparisons and discussions of the results are presented in chapter seven.

The second objective of this research is to investigate and analyse the driving cycles on a number of traffic calming corridors.

Driving cycle techniques are mainly used in the western world. This is because the main applications of driving cycle have been in the area of emission modelling. Since environmental impacts and emission analysis are not the most important issues on the national agendas in developing countries, these techniques therefore have been less recognised in these countries. These results are presented in chapter five.

The third objective of this research is to investigate the driving cycle on traffic corridors in a developing country.

In order to achieve this, data was collected from two traffic corridors in the city of Abu Dhabi (UAE) and analysed. Driving cycle for cars and for buses have been developed and analysed. These results are presented in chapter five.

The fourth objective of this research is to analyse and compare the obtained driving cycle results and draw conclusions on the possible impacts of various travel demand management policies.

Furthermore, the driving cycle analysis and investigations have always been based on the analysis of speed-time diagrams and investigations of average values of speeds, acceleration, and deceleration, cruising and idling. There are no further statistical or analytical techniques such as regression analysis for example to attempt to analyse and investigate mathematical models for the relationships between those parameters.

The final objective of this research therefore, is to attempt using regression analysis techniques to establish mathematical relationships between speeds and the other performance parameters discussed above.

1.4 Objectives of the thesis

The main aim of this research therefore is to investigate impacts of travel demand management measures using driving cycle characteristics. Furthermore, this study will also develop real world driving cycles for the cities of Edinburgh and Abu Dhabi and to investigate their impacts on emissions. The specific objectives of this research are:

1. ***To investigate and analyse in more details the impacts of bus lanes on traffic using the analysis of the driving cycles of buses on a number of corridors.***
2. ***To investigate and analyse the driving cycles on a number of traffic calming corridors.***
3. ***To investigate the driving cycle on traffic corridors in a developing country.***

4. ***The fourth objective of this research is to analyse and compare the obtained driving cycle results and draw conclusions on the possible impacts of various travel demand management policies.***
5. ***The final objective of this research therefore, is to attempt using regression analysis techniques to establish mathematical relationships between speeds and the other performance parameters discussed above.***

1.5 Conceptual framework for the study

To achieve the above aims and objectives, the framework presented in Figure 1.1 is adopted which consists of the preliminary investigation, calibration and validation of driving cycles, assessment of different TDM measures, analysis of results and comparisons and evaluations. The overall approach agreed for the research is illustrated under the following tasks.

1. Preliminary investigations and literature review.
2. Selection of the study corridors and TDM measures.
3. Calibration and validation of a car and bus driving cycle for Edinburgh and Abu Dhabi.
4. Analysis of results, comparisons and evaluations

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

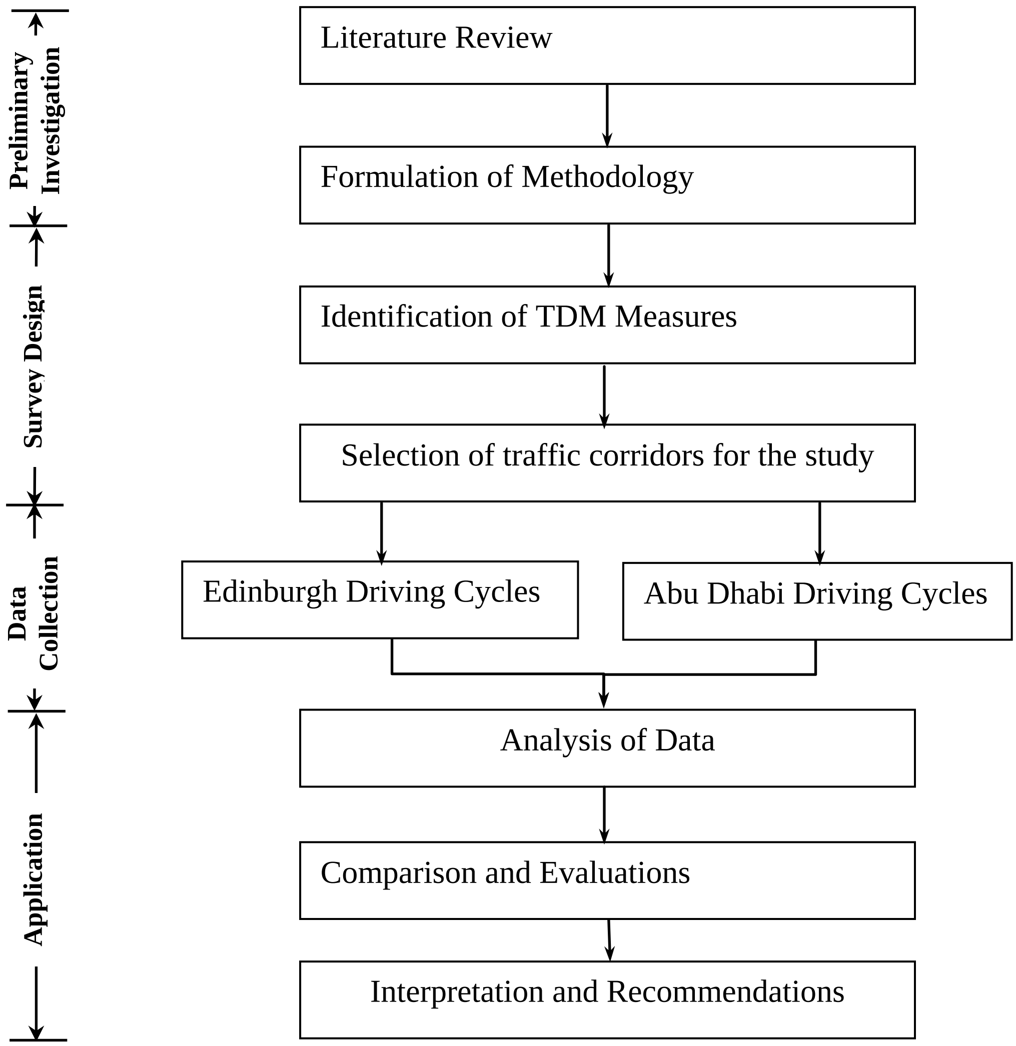


Figure 1.1: Conceptual framework of this research

Preliminary Investigations include a thorough literature review of the subject area in particular the review of different TDM techniques and their impacts in different cities. The impacts in terms of emissions and overall network performance are explored. In the light of this literature review, a methodology is formulated which includes the selection of the study area and the TDM measures present there. In each study area important corridors with similar characteristics are identified and selected for pilot investigations. As mentioned earlier, in this research, Edinburgh and Abu Dhabi have been selected as study areas to carry out the investigation. To derive the driving cycle, the methodology includes the selection of the corridors which already have different TDM measures on them. More specifically, those corridors having bus lanes on them were selected in addition to ones which have speed calming devices. Next, proper vehicles were selected and volunteers to collect data were recruited. Data was collected for both peak and off-peak periods for the selected corridors. Figure 1.2 shows the selected process for carrying out driving cycles.

Proper vehicles were selected and volunteer to collect data were recruited.

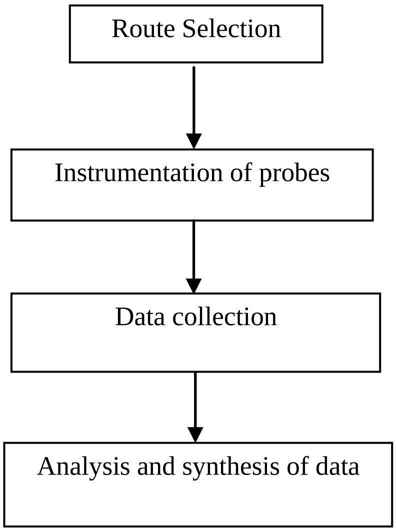


Figure 1.2: Framework of data Collection

Finally, the evaluation criteria for the assessment of different TDM measures were setup and the results were compared with different driving cycles.

1.6 Scope and limitations of the research

- The driving cycles were simplified because of the time and budgetary constraints. Classifications of driving cycle and associated factors (e.g. urban/rural, time of day, speed, engine size, and driver characteristics) could have been extended to include more factors, types of roads, times of day, types of vehicles, etc. For this research, only morning peak and afternoon off peak periods were selected and one type of vehicle was used for the runs.
- The number of corridors was limited to three bus corridors in Edinburgh and two in Abu Dhabi due to limitations of time, budget and personnel. Times of the day were

also limited to AM peak and PM for the same above reasons. Only one private car was used in all runs to avoid discrepancy in the data and to try to minimise errors.

- Only weekdays were selected for the data collection due to lack of manpower and budget.

1.7 Structure of thesis

Following this introductory chapter, the thesis begins by a review of the past research in the area of Travel Demand Management and driving cycles. The literature review reported in chapter two is mostly focused on building an understanding of effects of different types of TDM and their impacts on the network. The literature review on the TDM and its impacts suggest that they are important determinants which influence the network speed and performance. The chapter also details various driving cycles and their uses.

Case studies are presented in chapter three which begins by discussing the reasons for choosing these case studies, then the chapter proceeds with an overview of these case studies. The chapter then addresses the characteristics of the case studies in Edinburgh and Abu Dhabi.

Chapter four discusses the data collection in this work. The selected corridors, piloting the data collection is firstly presented then, the equipment used, the corridors and the assessment parameters are discussed.

Chapter five presents results and the preliminary analysis obtained from monitoring and measuring of performance of cars and buses on the selected corridors in the study.

Chapter six discuss the developing of the driving cycle. Chapter seven includes in-depth and detailed analysis of the preliminary results produced from the data on driving cycles.

Chapter eight has further analysis of the results which are presented and investigated using techniques of regression analysis. Finally, chapter nine concludes for the research of this study. A summary of the findings of each chapter is discussed, and finally suggestions for future work and a summary of the thesis as a whole are presented.

1.8 Novelty of the research

The novel aspects of this work include:

- Development of driving cycles for cars and buses on the same corridor for the purpose of investigating the detailed impacts of travel demand management policies.
- The analysis and investigation of driving cycles for traffic corridors in order to assess transport policies.
- The development of driving cycle for the Abu Dhabi city.
- Development of driving cycle for traffic calming corridors.
- The use of regression analysis and driving cycle analysis to model the performance of buses and cars on traffic corridors.

CHAPTER 2

LITERATURE REVIEW

The literature review is mostly focused on building an understanding of driving cycles as a method to study effects of different traffic demand management measures. It has been observed that the amount of literature available in this area has grown dramatically over the last two decades.

Driving cycles in the literature have mostly been used to assess emissions from various vehicles. Driving cycle analysis however has a great potential to be used to assess other transport policies. In this research, bus corridors and traffic calming measures are assessed using the principles of driving cycles.

2.1 Driving cycles

This section of the literature review will consider what constitutes a driving cycle; provide details of the most commonly used standardised driving cycles and outline city specific driving cycles.

Emissions due to transport are a major source of air pollution and a major contributor to global warming. Tzirakis et al. (2006) point out that emissions from transport vehicle are the main source of atmospheric pollution in modern cities. This situation is exacerbated by the increasing number of passenger cars, which has resulted in increased emissions and fuel consumption. According to Barlow et al. (2009) road vehicles emit a range of air pollutants due to the combustion of fossil fuels, which result in pollutants such as carbon monoxide, volatile organic compounds, oxides of nitrogen and particulate matter. These pollutants are regulated by European Union directives and these directives require all new light duty vehicle models to comply with particular emission standards. New light vehicle models must pass an emissions test before they can be approved for use in the European Union. It is therefore essential to have reliable knowledge "*about the sources and causes of the pollution, the technological and behavioural parameters of influence and the potentials of different* *strategies to reduce the pollution"* (Joumard 2007). Barlow et al. (2009) point out that the best way to ensure that an emission test is reproducible is to perform standardised tests in laboratory conditions, using emission models. Emission models are used to quantify the past, present and future effects of air pollutants due to transport.

2.1.1 Definition of a driving cycle

The literature review shows that there is consensus among experts regarding the definition of a diving cycle. A driving cycle for a vehicle is defined as *"a representation of a speed–time sequenced profile developed for a specific area or city*" (Saleh et al. 2010). Montazeri-Gh & Naghizadeh (2003) define a drive cycle as *"a speed-time sequence developed for a certain type of vehicle in a particular environment to represent the driving pattern with the purpose of measuring and regulating exhaust gas emissions and monitoring fuel consumption*". Barlow et al. (2009) states that a "*driving cycle is a fixed schedule of vehicle operation which allows an emission test to be conducted under reproducible conditions*". Drive cycles are generally defined in terms of vehicle speed and gear function expressed a function of time (Barlow et al. 2009).

2.1.2 The Benefits of driving cycle

A driving cycle is a series of data points representing the speed of a vehicle versus time. These can be produced by different cities to represent their local traffic and driving conditions. They can also be used to assess the performance of vehicles, control traffic emissions and as a tool for evaluating various TDM (Travel Demand Management)) measures and their effectiveness. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for example fuel consumption and polluting emissions.. It is widely used to estimate transport air pollutant emissions and in the building of databases for emission inventories. For example, driving cycles for private cars and light goods vehicle (LGV) are used to enhance traffic management systems, determine fuel consumption patterns and reduce transport impacts on health (Tzirakis et al., 2006; Saleh 2007; Hung et al., 2007). In literature a number of investigations of driving cycles were carried out to understand the local and national driving patterns and estimation of fuel consumption and emissions. These investigations started as early as 1978 when Kulher and Karsten (1978) collected data on various routes in different European cities with the use of on board measurement tools and developed the “Improved European driving cycle”. They adopted different assessment parameters for the development of improved driving cycle for Europe. During the same time, Kent et al. (1978) collected data using an instrumented vehicle which was driven over selected routes during the morning peak traffic period. The chase-car technique was used, whereby a vehicle is selected at random in the traffic and the survey vehicle simply follows this vehicle keeping approximately a constant distance during cruise conditions and allowing a time lag during acceleration and deceleration conditions. With the introduction of strict emission standards by the EU in 1990, the emission performances of the cars were tested using the ECE (Economic Commission for Europe) driving cycle. The new test procedures allowed reproducing one or several short and reproducible tests, in which driving cycles were generated by random simulation of speed and time curves, as a function of the distributions (probability densities) of the various modes and transitions including gear changes. The significant parameters were selected and were related to fuel consumptions in the UK. In 1995, the urban driving cycles for actual car use and operating conditions to measure emission was developed. The data was measured by a fleet of 58 instrumented vehicles, selected in six European cities: London and Derby in the UK, Cologne and Krefeld in Germany and Marseilles and Grenoble in France. The main parameters recorded at one second intervals were the date and times, vehicle speed, engine speed, throttle positions, fuel consumptions and the engine and ambient temperatures. Factor analysis performed identified the speed and acceleration level being the main influence on sequence variability. It classified the four classes of traffic conditions as congested urban, free flow urban, extra urban and motorway among the total trip and 14 urban cycles were produced with short extra urban cycles (Andre et al. 1995).

Andre, M. (1996) developed a set of driving cycles to assess private car fuel efficiency. Authors proposed a procedure enabling them to reproduce, in one or several short and reproducible tests, the significant parameters related to fuel consumptions. Two representative vehicle of the national fleet were instrumented and driven on 58 selected road routes. The vehicle speed, the engine rotation speed, the drive shaft torque, fuel consumption, brake and clutch applications, neutral conditions and information data (limit speed, etc) were measured. The data were corrected and prepared into homogenous conditions area and were then divided into acceleration, cruise and deceleration phases. These operation modes were analysed. The cycles were generated by random simulation of speed vs time curve, as a function of the distributions (probability densities) of the various modes and transitions. Cycle validation was performed by comparing speed and acceleration distributions with those of initial data and by comparing estimated energy amounts under driving and braking (deceleration) phases. Gear changes were considered a predominating factor of energy consumptions (and emission) and proposed simple observation based rules: average speed for up shifting, median speeds for down shifting.

Ergeneman et al., (1997) on the other hand, developed a methodology to generate a driving cycle from measured data for different vehicle groups, such as private cars, taxis, buses, and minibus, for various regions in the city possessing similar characteristics and developed a mathematical approach representing similar driving conditions to predict exhaust emissions and fuel consumptions. For emission inventory in the UK, an emission factor was developed by the Highways Agency in the UK, which has been detailed in the Design Manual for Roads and Bridges (DMRB) to provide guidance for the calculation of emissions generated by road traffic (Cloke, J., et. al 1999). In Volume 11 of the Manual, reference was provided on environmental assessment of trunk road schemes and air quality evaluation. In fact, the DMRB is not exactly an emissions model, but rather a step-by-step methodology for the calculation of road emissions. The average speed emission factors included are related to hot engines, and were derived from measurements made by the TRL (Transport Research Laboratory) and factors determined by the CORINAIR working group. Andre et al., (2004) derived urban driving cycles based on the actual car use and operating characteristics to measure emission based on kinematics sequence methodology for European traffic conditions. The following sections discusses in detail the driving cycle for cars in different cities.

2.1.3 The use of drive cycle in emissions measurement

Driving cycle data is used to accurately estimate transport pollutant emissions and for building emission inventory databases. There have been studies throughout the world to determine the driving cycles for private cars, light goods vehicles and motorcycles, as part of traffic management systems. This data is also used for determining fuel consumption patterns and reducing the adverse impacts of transport on human health (Saleh et al. 2010). It can also be used for engine testing or durability of drive train (Barlow et al. 2009).According to Watson (1978) emission data obtained from drive cycle analysis provides data for analysts in predicting air pollution and planning mitigation measures. The data is also useful for car manufacturers in design and marketing and ensuring that their vehicles comply with national and international regulations.

The literature review indicates that emissions are dependent on a number of variables. Faiz et al. (1996) suggests that vehicle emissions are variable and are affected by driving patterns, behaviour, traffic speed, altitude, temperature, type and age of vehicle. In addition to all these variables, differences in operating conditions also affect the emissions for a given vehicle. Montazeri-Gh & Naghizadeh (2003) maintain that drive cycles can be used to assess vehicular emissions and fuel economy. Driving patterns and behaviour varies from country to country and from area to area meaning that it is difficult to apply drive cycles developed for one city to another, even if it is in the same country. This means that most research into vehicular emissions deals with the development of drive cycles using real world driving tests. Barlow et al. (2009) agrees, suggesting that emission levels are dependent on a number of variables including model, size and type of car, the fuel used, technology and the actual vehicle mileage, as well as operational factors such as speed, acceleration, deceleration and gear changes.

Driving cycles can be divided into steady state cycles and transient state cycles. Barlow et al. (2009) defines a steady state cycle as "*a sequence of constant engine speed and load modes*" which are used mainly in testing heavy-duty diesel engines. Rakopoulos & Giakoumis (2009) point out that traditionally the study of vehicle engines has been based on steady state performance, however it is now accepted that in reality a very small proportion of a vehicles operating pattern is actually steady state, which is probably only achieved when driving along a motorway at a steady pace. Rakopoulos & Giakoumis (2009) suggest that more realistic models such take account of the unsteady or transient state patterns.

2.1.4 Driving cycle data collection

Data can be collected directly from target vehicles by installing data acquisition equipment in the vehicles, alternatively data can be collected using a chase car, which potentially reduces the possibility of affecting normal driver behaviour in the target vehicle and therefore results in useful realistic data. Another method of collecting data is using field survey questionnaires. A typical example is the development of a driving cycle for Edinburgh to model realistic driving patterns based on data measured and recorded from actual traffic conditions, using the car chase technique (Esteves-Booth 2001).

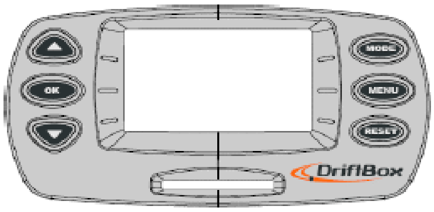
Saleh et al. (2010) point out that data can be collected using micro–simulation methods based on psychophysical car–following models, which can also reproduce realistic traffic flows based on different real–world driving conditions. One of the disadvantages of these techniques is that they are expensive and can be difficult to operate. It is also difficult to collect accurate data if the collection equipment is in the vehicle as this can affect the driver's behaviour, which distorts the results.

2.1.5 Performance box

2.1.5.1 The GPS device (Performance box)

The performance box (PB) device is a perfect tool for measuring vehicle or driver performance accurately (See Figures: 2). The PB device has the ability to monitor vehicle speed, throttle position and mass air flow. The device also automatically stores the date and time of each individual recording. The data can then be downloaded to a desktop computer (PC) and analysed. The private vehicle will have two occupants, the driver and an assistant who records further information, such as, abnormal traffic or weather conditions, distances, as well as starting and end times at each segment of the route. All these parameters will be finalized during the pilot survey (Manual of Performance Box, 2008).

PerformanceBox Keypad



▲	Used to show next screen, or to navigate menu.	MODE	Changes Mode.
OK	Select the menu item that is highlighted on the screen and used to show Score Code.	MENU	Accesses the relevant menu, or will exit from current menu.
▼	Used to show previous screen, or to navigate menu.	RESET	Resets totals, averages and peaks if held for 1.5s. Hold for 5s for global Reset.

Figure 2.1: Performance box keypad

Performance Box has a display screen mode that shows a large digital speed value and compass. In open conditions, Performance Box has a velocity accuracy of 0.1km/h, which is useful for checking the accuracy of your vehicle's speedometer. In this mode there are also Odometer and Altitude display screens. This display has a 'Point of Interest' facility, which alerts you as you approach the position of a point of interest such as a safety camera or service station. POI files can be created and edited for custom use. Performance Box can help measure the power developed by the car's engine, when the right weight of vehicle is set.

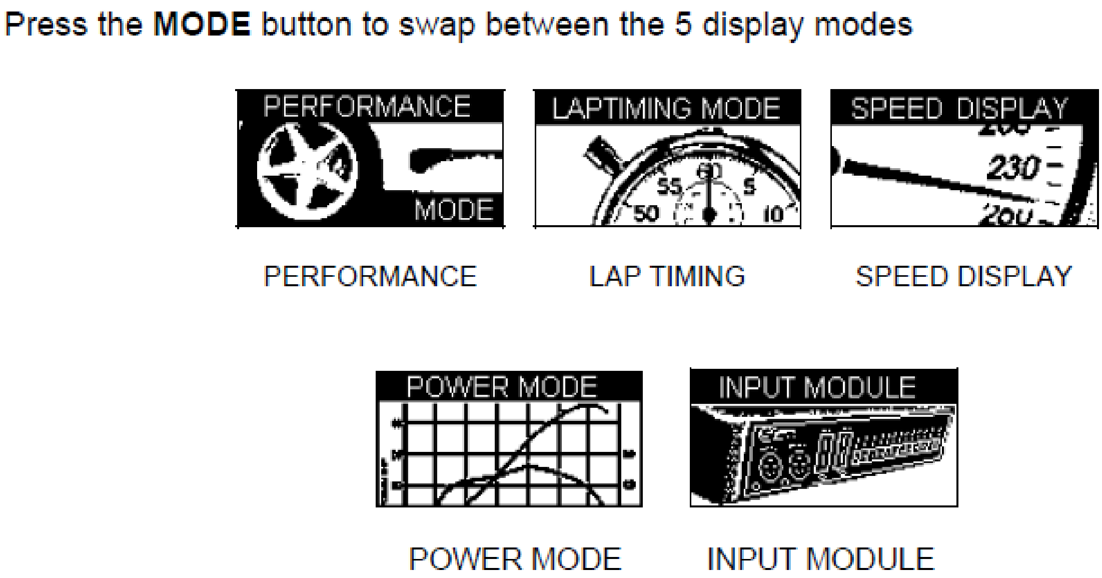


Figure 2.2: Changing performance box modes

Performance Box is based on the Race logic VBOX, which is used by the majority of Car Manufacturers, Tyre Manufacturers and car magazines around the world to assess performance.

With Performance Box it is very easy to measure acceleration times, braking distances, quarter mile times and many more. There are a number of configurable screens that show specific test results such as 0-60, 0-100, 0-100-0, ½ mile and ¼ mile. Vehicle modification can be readily assessed and given specific improvement parameters, the perfect tool for any tuning enthusiast. Because it is very easy to edit the test ranges, Performance Box is a very powerful tool for use in many different kinds of vehicle testing.

2.1.5.2 Lap timing

Displaying your Lap times as you drive around a circuit is simple with Performance Box. You can display your last and best Lap times and Lap count, and also display split times for up to six specified split points around the lap. The split files can be saved and reused should you attend the same circuit again, guaranteeing consistent data. You will be able to catalogue and review your performance over any given period of time.

Figure 2.3: Lap timing display

2.1.5.3 Speed display screen

Performance Box has a display screen mode that shows a large digital speed value and compass. In open conditions, Performance Box has a velocity accuracy of 0.1km/h, which is useful for checking the accuracy of your vehicle's speedometer.

2.1.5.4 Power calculations

Performance Box can help you to measure the power developed by your car's engine, either at the wheels or flywheel. Having set the vehicle weight, results are calculated from the measurements taken by the fast GPS engine to give you useful guidelines to the car's brake horsepower or kilowatt output. Because these calculations are made from the GPS data rather than accelerometers, your results are likely to be more consistent and accurate.

2.1.5.5 Data logging

For drivers keen to improve their lap times and get valuable feedback on technique, Performance Box includes a sophisticated, fully functioning data logging package. If used with a 64mb SD card, Performance Box can log up to 50 hours of continuous data, which can be analysed in great detail in the available software.

This software allows graphical analysis of acceleration, braking, cornering and lap times, and if the Performance Box is used in conjunction with a Micro Input Module, data from the vehicle itself (such as RPM and throttle angle) is recorded alongside the GPS parameters. You can overlay up to four files, and you get an accurate track map to compare your driving line between different laps. The software also features a graph measure tool, allowing for precise analysis of performance figures. Data-logging capabilities are further enhanced by automatically generated text data on the SD card (Manual of Performance Box, 2008).

2.1.6 Drive cycle models

There are a number of emission models available and all are slightly different. According to Montazeri-Gh & Naghizadeh (2003), there are a number of different driving cycles developed to represent different types of vehicles and driving behaviour. Faiz et al. (1996) suggests that the most commonly used are the US Federal, the United Nations Economic Commission for Europe (ECE) and the Japanese test procedure.

2.1.6.1 USA driving cycle

In the USA, a driving cycle has been developed called the FTP-75, which is a transient test cycle used for emission certification testing of cars and light duty vehicles (Montazeri-Gh & Naghizadeh 2003). In this test procedure a light vehicle, typically a car or light goods vehicle is driven on a chassis dynamometer on a predetermined driving cycle. Samples of the exhaust emissions are collected throughout the procedure in a constant volume sampling system. According to Faiz et al. (1996) the driving cycle which lasts for 2,475 seconds is meant to reflect the varying nature of urban vehicle operation, with a average driving speed of 31.4 km/hr. The test is carried out in three phases, cold start, hot stabilised and hot start. The procedure starts with a 12-hour vehicle soak followed by a cold start where temperatures range from 20^0 to 30^0C. The emission results are calculated as weighted average of emissions measured for each of the three phases.

Experts maintain that one of the main disadvantages of this test procedure is the narrow speed range and the fact that the procedure does not represent realistic driving conditions. Faiz et al.

(1996) points out that the test procedure does not cover the full range of speed and acceleration conditions experienced by vehicles operating in the real world. Experts also maintain that FTP-75 provides a poor simulation of air conditioner operations. The model has been improved by adding supplementary models such as the Supplemental Federal Test Procedure (SFTP), which is used to represent the engine load and emissions associated with vehicles possessing air conditioning units. There is another supplementary test procedure called the US06 Supplemental Federal Test Procedure which was designed to address and improve the FTP-75 test cycle in the representation of "*aggressive, high speed and/or high acceleration driving behaviour, rapid speed fluctuations, and driving behaviour following start up"* (Faiz et al. 1996).

Emission testing for light duty vehicles is carried out using the "IM-240" test based on a chassis dynamometer schedule and used in a number of States for inspection & maintenance programmes. Some of the national driving cycles have been developed further to represent driving styles for individual states. For example "LA92" is a dynamometer driving schedule for light duty vehicles developed by the California Air Resources Board, represents a more aggressive driving cycle with higher speeds and rates of acceleration, with less stopping and less idles time than allowed for in the federal FTP-75.

2.1.6.2 European driving cycles

Driving cycles used for certification of emissions from light duty vehicles in Europe include the Economic Commission of Europe (ECE) and the New European Driving Cycle (NEDC). These driving cycles are based on a chassis dynamometer (Montazeri-Gh & Naghizadeh 2003). The European procedure consists of three tests, lasting 780 seconds and covering 4.052 km with an average speed of 18.7km/hr. The first test measures the exhaust emissions produced in a driving cycle on a chassis dynamometer, where the driving cycle is based on a typical urban area in Europe with 15 linked driving modes. The procedure has a maximum allowable speed of 50km/hr. The test starts with the vehicle soaking for a minimum of six hours at a temperature in the range of 20^0 to 30^0C. The engine is then started and left to idle for 40 seconds, followed by four test cycles without interruption. The second test takes samples of carbon monoxide concentrations from the exhaust emissions immediately after the last cycle of the first test. Crankcase emissions are measured in the third test.

The European test procedure has been criticised for being even less realistic than FTP-75 because the results are based on low rates of acceleration. The test uses an acceleration rate of 3.75km/hr/sec sustained for 4 seconds during the first peak, 2.61 km/hr/sec in the second peak and 1.92km/hr/sec in the last peak, which equates to less than one-fifth the rate observed in actual driving conditions. The European test procedure includes an extra-urban driving cycle (EUDC) which lasts for 400 seconds with an average speed of 62.6km/hr and a maximum speed of 120km/hr (Faiz et al. 1996). Barlow et al. (2009) points out that the New European Driving Cycle which is used to approve light vehicles for use in Europe is based on unrealistic steady state conditions. The test uses a cycle where there are periods of constant acceleration, deceleration and speed, which Barlow et al. (2009) argue does not reflect real driving operations, given that real world driving patterns are transient. Japan uses the MVEG-A drive cycle for emission certification and fuel economy of light duty vehicles (Montazeri-Gh & Naghizadeh 2003).

Faiz et al. (1996) maintains that the American and European test procedures are commonly used in other countries and that these test procedures have many commonalities. For example the volumes of emissions are measured by operating a test vehicle on a chassis dynamometer while collecting the exhaust emissions in a constant volume sampling system. The principal difference in the testing procedures is the driving cycle for the light duty vehicles. The US test involves transient variations in speed and load, which are considered very similar to actual driving, whereas the European and Japanese procedures are based on a "*series of steady state operating conditions*" (Faiz et al. 1996). The European test is simpler than the US test procedure and the maximum acceleration rate at 3.75 km/hr/sec being significantly less than the US test. However it is suggested by Faiz et al. (1996) and Barlow et al. (2009) that none of these test procedures accurately reflects real driving patterns and this has led to other driving cycles being developed. Barlow et al. (2009) suggests that these driving cycles' model emissions based on varying the average speed of a vehicle trip, expressing emissions as grams of pollutant per vehicle kilometre. Barlow et al. (2009) suggests that there are limitations to this method of analysis based on average speed models, since it is difficult to assess ranges of vehicle operation and emissions behaviour in average speed scenarios. A typical example of this is vehicle emissions from a vehicle with a catalytic converter, in this type of vehicle the greatest output of pollutant is in the short sharp peaks which occur during gear changes and acceleration.

2.1.7 City specific driving models

As mentioned earlier, this literature review highlights the fact that emissions are based on driving patterns and driving patterns are variable depending on speed, temperature, model of car, maintenance of that vehicle and many other variables. This suggests that emissions for vehicular operations will vary from place to place and given the importance of quantifying these pollutants this has led to the development of city and/or country specific models.

2.1.7.1 Artemis driving cycle

This driving cycle represents the European driving behavior for passenger cars. It was developed within the European research project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems). The Common ARTEMIS Driving Cycle (CADC) consists of three parts, urban, rural (i.e. extra-urban) and highway. All three parts can be used independently, because all start and end with zero speed (Andre et al., 2004; Vasic and Weilemann, 2006). Figure 2.4 shows the driving cycle in three different categories of roads (urban, rural and motorway). In addition to this, Andre et al., (2006) investigated the driving cycle for different categories of cars i.e. specially designed high and low power cars. The cars were considered different in their driving conditions, characteristics of driving conditions and vehicle usage. Actual driving conditions of the high and low power car were derived using statistical tests as shown in Figures 2.5 and 2.6 respectively. In addition, emission measurements on 30 representative cars of French fleets were carried out to develop the emission standard.

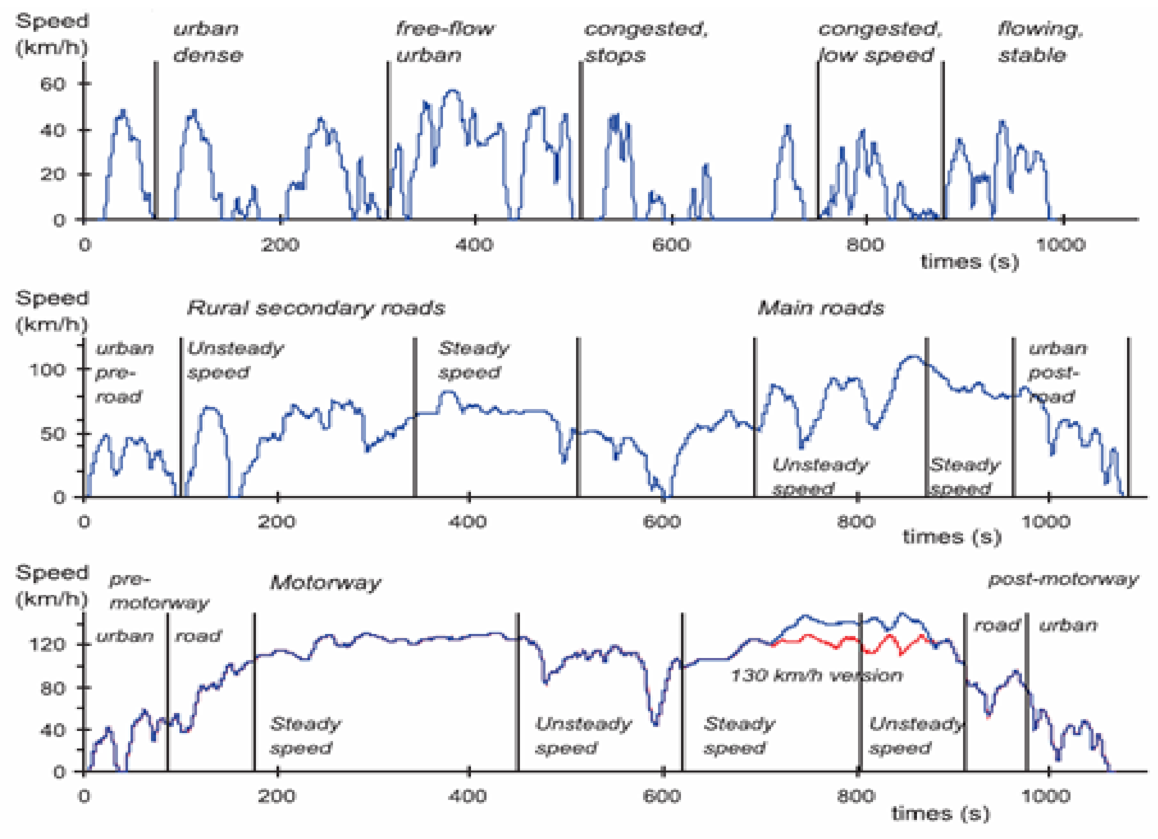


Figure 2.4: Figure 2.4 ARTEMIS urban, rural and motorway driving cycles

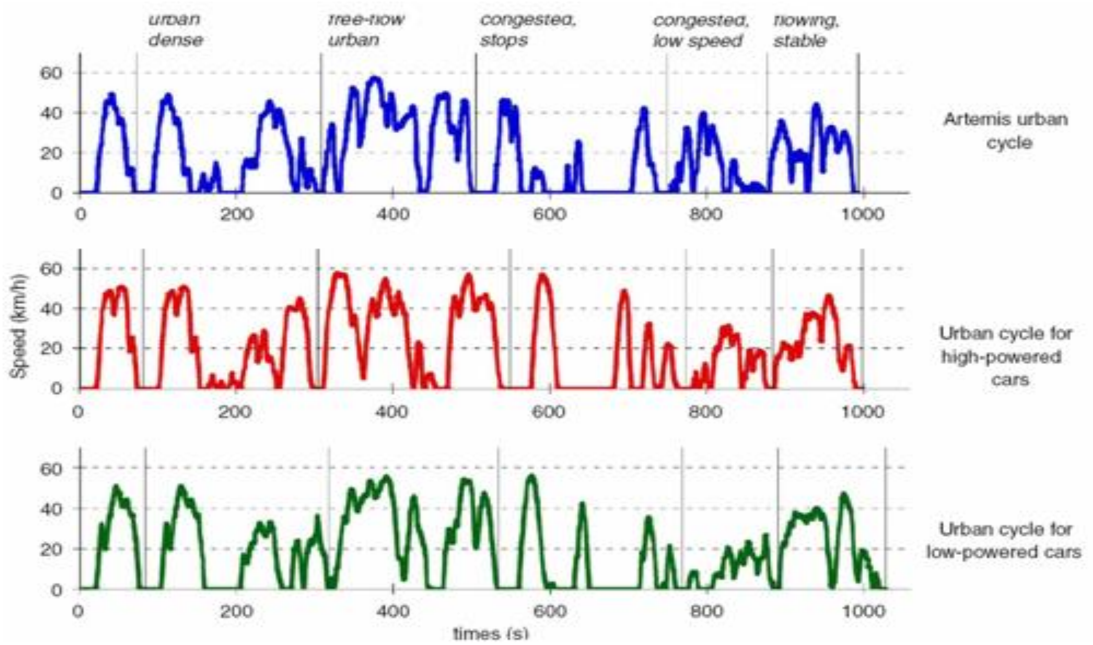


Figure 2.5: ARTEMIS driving cycle for high and low-powered cars

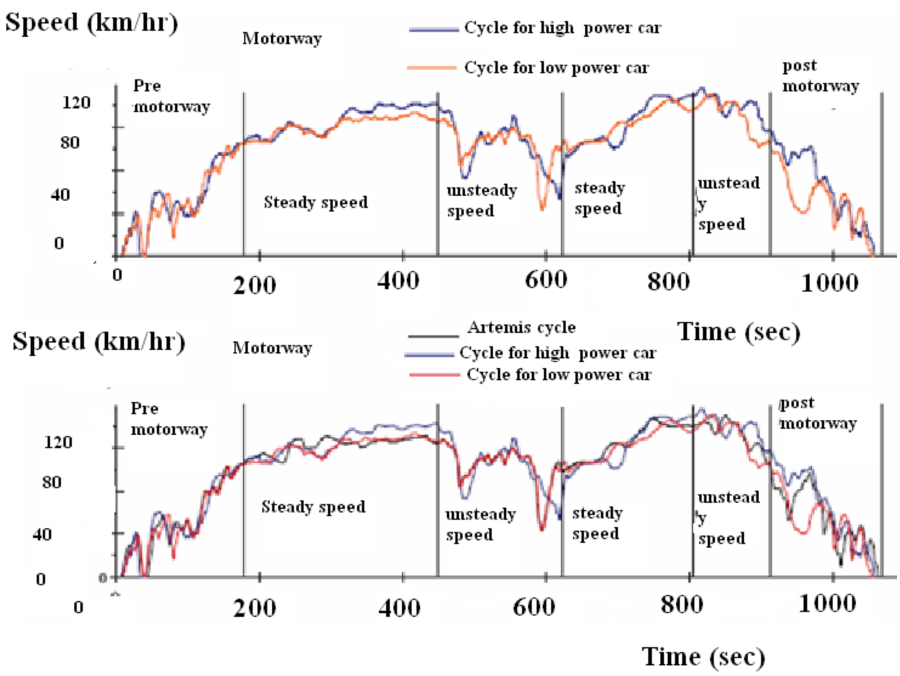


Figure 2.6: Motorway driving cycle for high and low powered cars and ARTEMIS cycle

The ARTEMIS project (Assessment and reliability of transport emission models and inventory systems) was developed to provide researchers with a "*harmonised methodology for emission estimates at the national and international level*" (Joumard 2007). The Artemis model for cars and light goods vehicles is based on data derived from over 3500 tests with more than 150 vehicles, with specific measurements of regulated and non-regulated pollutants. This model contains a set of sub-models. According to Joumard (2007) the base model calculates hot emissions for each vehicle category in different driving behaviours. It includes five alternative models including a simplified model, which uses the same data as the main model and considers driving behaviour with average speeds. It also has a continuous or kinematic model, which takes account of aggregated kinematic parameters. The Artemis model also has two instantaneous models, which require kinematic data and can be adapted to different usages for assessing both national emissions and local traffic controls. This system allows researchers to consider the influence of parameters, such as cold start, air conditions, vehicle mileage, temperature and humidity, on emissions (Joumard 2007). Barlow et al. (2009) points out that within the ARTEMIS model there is a utility called Art.Kinema which can be used to assess a broad range of descriptive parameters to define a specific driving cycle, such that different driving cycles can have different time and speed resolution parameters. This sub-model divides the parameters into groups such as distance related, time related, speed related acceleration related, stop related and dynamics related. Within each of these groups, there are a number of descriptive parameters, which can be used in the driving cycle, for example in the time related group, descriptive parameters include total time, driving time, cruising, time spent accelerating or decelerating, time spent parking and standing time. Acceleration parameters include average acceleration, number of accelerations, positive or negative accelerations and number of accelerations per km travelled (Barlow et al. 2009).

2.1.7.2 Tehran driving cycle

Montazeri and Naghizadeh (2003) developed the driving cycle for simulation of vehicle exhaust gas emissions and fuel economy in the city of Tehran (Figure 2.7). The speed was computed by the speedometer of the vehicle whereas the device was an electronic network that works together with a laptop computer as a data logger. The output of the network was connected to the computer, and there where the frequency of pulse signal was converted to vehicle speed. Two parameters were used for analysing micro-trips i.e. average speed and idle time percentage (%). The proportions of time spent on four-road category in the whole set recorded data were used to find the duration of the cycle length (sec). It was observed that as the average acceleration and deceleration of a cycle increase, the emissions and fuel consumption increases. The Tehran Car Driving Cycle has greater maximum acceleration and deceleration but smaller average acceleration and deceleration, than the FTP cycle, implying lower emissions and lower fuel consumptions.

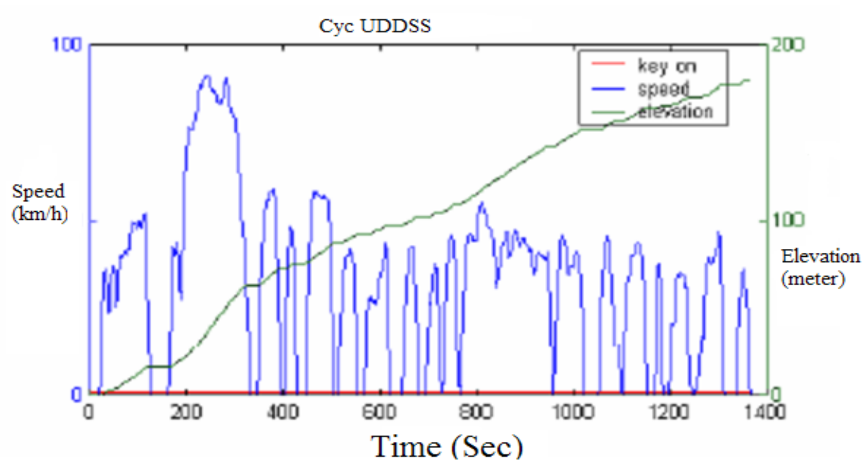


Figure 2.7: Tehran driving cycle

Historically analysis of emissions in Tehran used the American or European driving cycle test procedures. Montazeri-Gh & Naghizadeh (2003) developed this driving cycle specifically for the city as it was believed that other standardised procedures did not accurately reflect driving patterns in the city. The driving cycle was developed using a measuring device fitted to vehicles to record speed. The driving cycle is based on micro-trips where a micro trip is defined "*as an excursion between two successive time points at which the vehicle is stopped* "(Montazeri-Gh & Naghizadeh 2003). Data on acceleration, cruise and deceleration modes was collected and analysed for each micro-trip. The data was then used to calculate the following driving parameters, average speed, maximum speed, acceleration, deceleration, and the number of "micro-trips" for each car trip. This data also meant that the model could be compared to other standardised models. By comparing idle time to average speed distribution traffic conditions in Tehran were divided into four categories, congested urban condition, urban condition, extra urban condition and highways. The first category, "*Congested Urban Condition*", categorised by low driving speeds typically less than 10km/hr and varying idle times. The second category was "*Urban condition*" which represents non-free flows with moderate idle time and typical speeds of 10 to 25km/hr. "*Extra urban condition*" representing relatively free flow conditions with low idle times and average speeds of 25-40km/hr. The last category is "*Highways*" representing completely free flowing traffic with very low idle times and average speeds of over 40km/hr. The data collected from the micro-trips was statistically analysed to develop TEH_ CAR the Tehran driving cycle. The study included a comparison of results from Tehran driving cycle to patterns of other countries by comparing data from TEH _ CAR with European standards and American standard driving cycles.

Table 2.1: Montazeri & Naghizadeh driving cycle

Cycles

	HC	CO	NOx	Fuel Consumption
TEH_CAR	.937	6.157	1.121	6.1
FTP72	.979	6.785	1.446	6.0
ECE	4.01	15.520	1.780	8.1
EUDC	1.081	6.885	1.668	5.3
ECE+EUDC	1.004	6.752	1.436	6.1
J10-15 mode	1.562	8.585	1.532	7.0

This comparison established that driving patterns of Tehran were similar to FTP, with similarities including aggressive acceleration and deceleration. However, as shown in Table 2.1 above, the Tehran driving cycle gave very different output from the European driving cycle models. TEH _ CAR also established a link between driving conditions, fuel consumption and vehicles exhaust emissions and found that as average acceleration and deceleration of a cycle increase, there is a corresponding increase in both fuel consumption and vehicle emissions (Montazeri-Gh & Naghizadeh 2003).

2.1.7.3 Hong Kong driving cycle

Tong et al., (1999) used an instrumented diesel vehicle along two fixed routes located in two urban districts in Hong Kong to develop a standard driving cycle for the urban areas of Hong Kong. The typical driving cycle is presented in Figure 2.8. In developing the standard driving cycle for Hong Kong, nine parameters were calculated from on-board survey data. The methodology included the selection of twenty short driving periods, each bound by idle times. Ten such cycles were developed and the best cycle was finally selected with minimum total percentage error. The Driving Cycle revealed that Hong Kong had more idle, acceleration and deceleration times when compared to those of the European and American standard driving cycles.

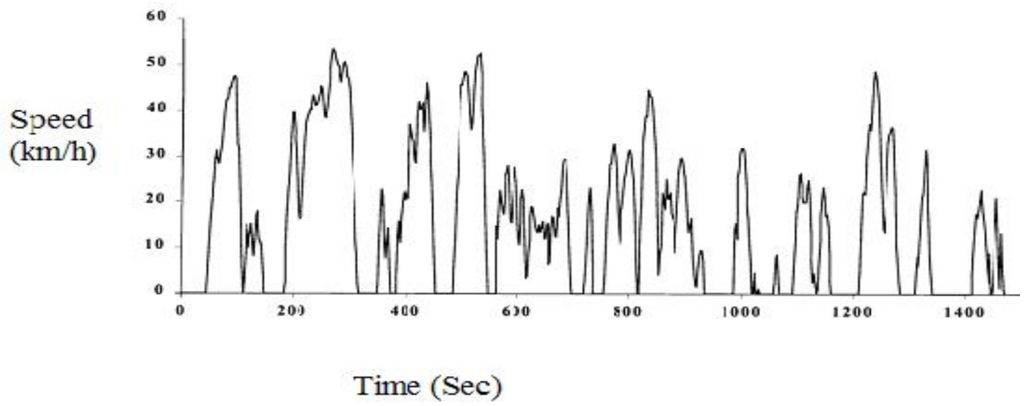


Figure 2.8: Hong Kong driving cycle

The Hong Kong diving cycle is based on "*on-road*" speed time data, which was collected by a diesel vehicle fitted with measuring and recording equipment. The vehicle collected the data along two fixed urban routes in the city. The data was analysed and compared to other driving cycles such as the FTP-75 and ECE. A study carried out by Tong (1999) found that none of these standard driving cycles matched the data collected specifically for Hong Kong, so a city specific driving cycle was developed for the city.

Hung et al., (2007), on the other hand developed three driving cycles for three traffic conditions (urban, sub-urban and highway driving behaviours, see Figure 2.9). The data was collected with the car chasing technique along nine selected representative routes during the morning peak hours.

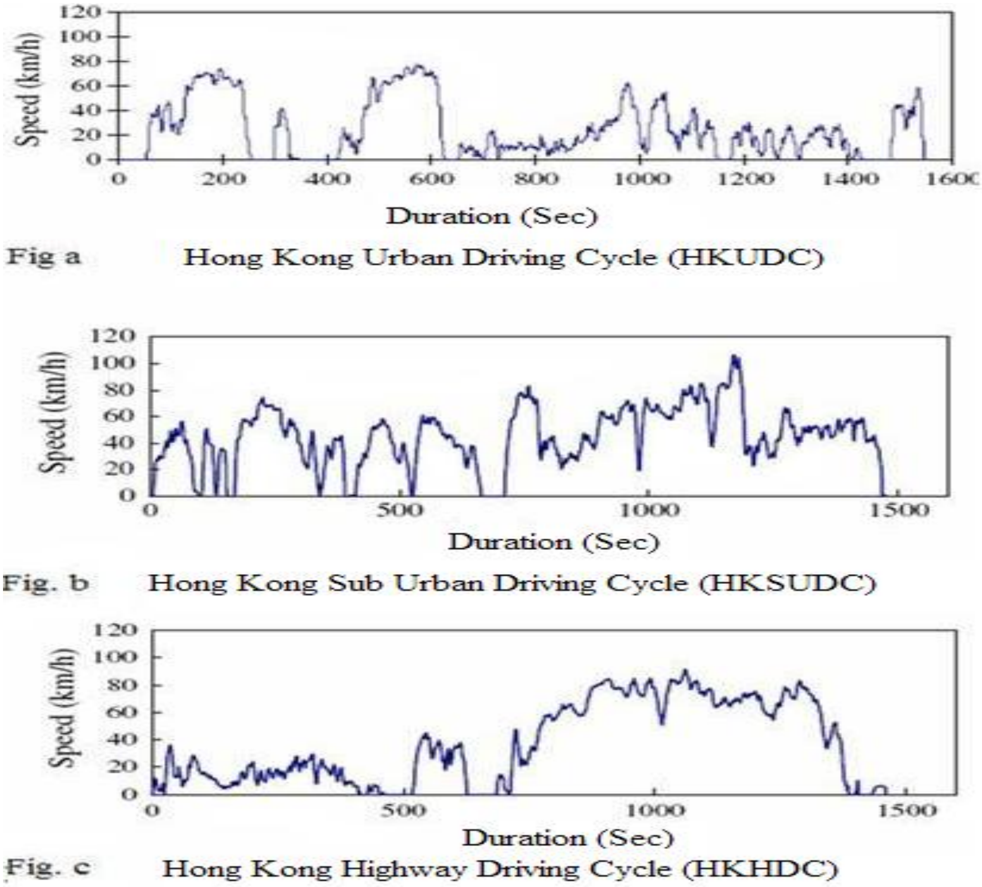


Figure 2.9: Hong Kong highway driving cycles (a) Urban (b) Suburban (c) Highway

2.1.7.4 Athens driving cycle

The transport network is growing in Athens, with rapidly changing vehicle use and driving patterns. This has led to growing concern with respect to the increase in atmospheric problems in the city, largely due to vehicle emissions. A specific driving cycle was developed for Athens because according to Tzirakis et al. (2006), the typical driving profile used in standard procedures did not represent typical driving cycles in Athens. Standardised procedures such the European driving cycle, FTP75 and the Japan 10-15 procedures were based on a complicated series of accelerations, decelerations and frequent stops using a laboratory chassis dynamometer which did not represent driving patterns in Greece or more specifically Athens. The Athens driving cycle is based on real world driving data, which was collected over a two-year period on the Athens road network. This data was then analysed and used to develop the Athens driving cycle. The test procedure lasts for 1160 seconds covering a distance of 6.512km, at an average velocity of 20.21km.hr and a maximum velocity of 70.86km/hr. The driving cycle is presented in Figure 2.10.

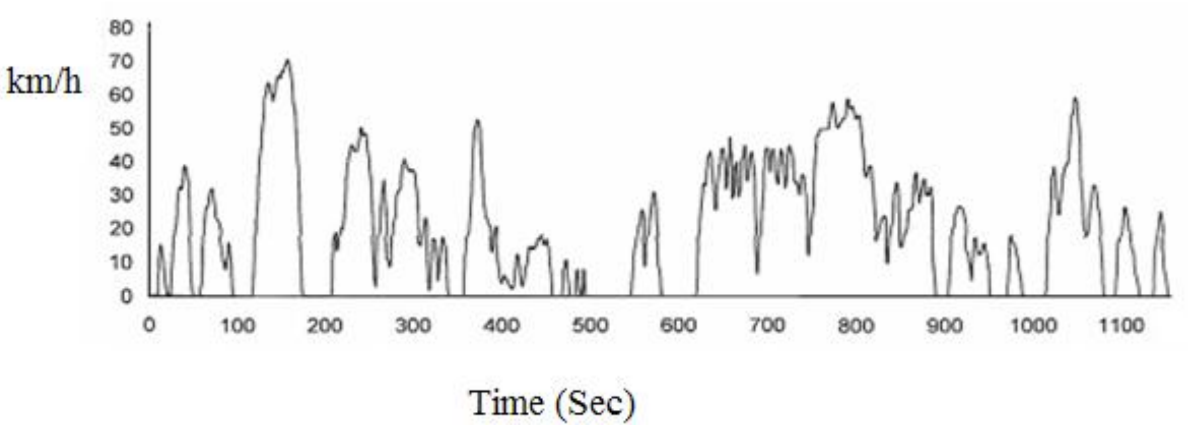


Figure 2.10: Athens driving cycle

Table2.2: Comparison of Athens driving cycle with European driving cycles (Tzirakis et al. 2006)

Table 1. Typical parameters of ECE 15, EUDC, NEDC and ADC (2002 data)

	ECE 15	EUDC	NEDC	ADC
Distance	4×1,013=4052 m	6955 m	11007 m	6512 m
Duration	4×195=780 sec	400 sec	1180 sec	1160 sec
Mean Speed	18.7 km h^{-1}	62.6 km h^{-1}	33.6 km h^{-1}	20.21 km h^{-1}
Max. Speed	50 km h^{-1}	120 km h^{-1}	120 km h^{-1}	70.86 km h^{-1}

The Athens driving cycle was tested against the new European Driving cycle, using three different classifications of passenger cars. The results of this comparison showed that the

Athens driving cycle nitrogen oxides are 2.5 times higher than, either the ECE or NEDC cycles. The Athens cycle also recorded higher carbon monoxide levels with no variation in hydrocarbon levels (Tzirakis et al. 2006).

2.1.7.5 Edinburgh driving cycle (EDC)

Edinburgh driving cycle (EDC) was developed by using car chasing technique on six routes of Edinburgh (Booth et al. 2001). The EDC was completely an urban cycle (i.e. does not include motorways). 60 % of the times were spent in acceleration and deceleration activity is compared with the European Driving cycle (ECE) which has one third of the total time in acceleration and deceleration. The reason for this discrepancy is that the EDC is the real representation of traffic in EDC, while the ECE is a synthetic cycle, which uses simplified modes (Andre, 1996). The typical EDC is presented in Figure 2.11. In all, 1027 data sets were collected using an instrumented vehicle. The vehicle was equipped with an instrument which recorded on-board data and stored it every second. The data was recorded for two months, from Monday to Sunday in the first phase and two weeks in the second phase on six different routes with desired driving instructions. The data was analysed using computer and statistical analysis techniques. A new methodology called TRAFIX (Traffic Flow Index) was developed to calculate the representative driving cycle.

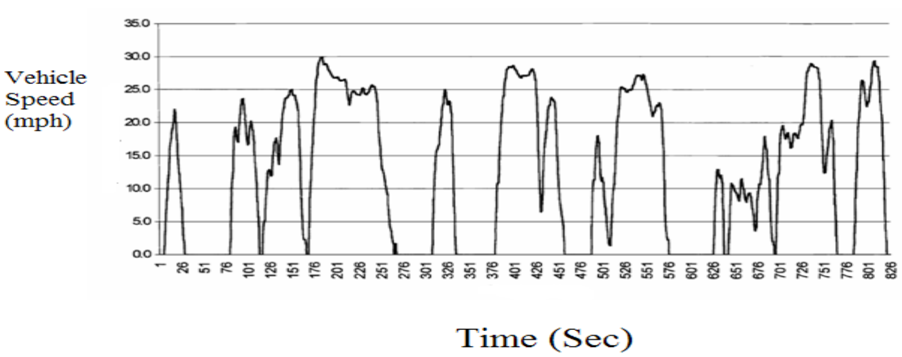


Figure 2.11: Edinburgh driving cycle

2.1.7.6 Sydney driving cycle

The Sydney driving cycle was developed by Kent et al. (1978) involved a survey of Sydney morning peak hour traffic. The data was collected using an instrumented vehicle, which was driven over the selected routes during the morning traffic peak (6:30 - 9:15 am) during weekdays. The results revealed that average speed and percentage idle time were close to the

U.S. Federal Driving Cycle values but root mean square acceleration was significantly higher. The joint speed-acceleration relative frequencies for the Sydney data were also markedly different to the FTP cycle. Sydney cruise speeds were centred on around 48-56 km/h with an even distribution of acceleration and deceleration at low speeds. Dominant cruise modes occurred at 32.4 km/h and there were significant contributions at speeds around 80 and 88 km/h. The U.S. cycle spends significant time at higher speeds and has two dominant acceleration peaks at low speeds. A short driving cycle of 10 m 37 s duration designed to yield the same statistics and emissions as the overall survey data was synthesised. A driving segment consists of a portion of the speed-time trace from any of the data bounded by an idling mode at either end and usually of about two minute's duration. Numerous segments were selected and the traces were first visually inspected for any abnormal characteristics. The average speed, percentage idle time and root mean square acceleration together with the predicted emissions were calculated for each segment. The cycle shown in Figure 2.12 was developed by making up the characteristics of the representative cycle.

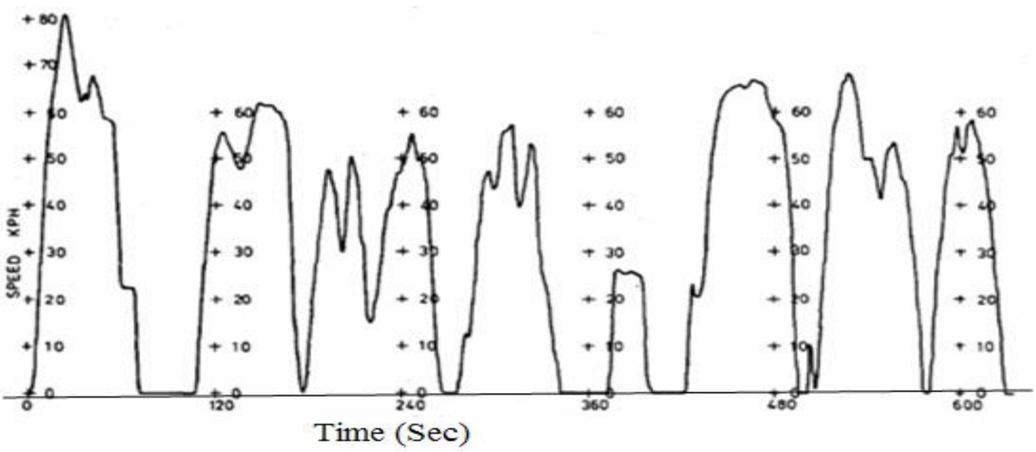


Figure 2.12: Sydney driving cycle

2.1.7.7 Melbourne driving cycle

Melbourne Driving Cycle was developed when data was collected at the morning peaks at different road sections of the Melbourne city (Watson et al., 1982). The purpose of the cycle was to provide the basis for a more realistic assessment of the emissions and fuel consumptions for Melbourne driving conditions.

2.1.7.8 Delhi driving cycle

Gandhi et al., (1983) used the instrumented car to study the driving patterns of the Delhi travellers. A comparatively small car was used to collect the data because major car types in Delhi are comparatively smaller engine cars. The capacity of the car was 1000 cm^3. The data was collected along the four representative routes. The car was used to record fuel consumption, trip length, trace of speed and change of speed with time, and time spent in various speed blocks.

2.2 Transport problems in developed countries

Transport related environmental problems and congestion is of major concern for all the transport managing departments in almost all major cities of developed countries. With increasing awareness towards environment, coupled with its rapid degradation, has created serious challenges for the today's transport planners and managers. In addition to this, transport safety and crash prevention has also remained a main focus for modern metropolitans.

2.2.1 The environmental impacts of vehicle travel

Car travel has a number of positive benefits, including increased mobility and freedom to travel. However, there are serious disadvantages to the motor vehicle including air pollution and contributing to greenhouse gases and global warming (Tyler Miller & Spoolman 2011). According to Corrales et al. (2000) there are five basic groups of transportation activities that adversely affect the environment, including the construction of transportation infrastructure such as roads, manufacturing of vehicles, vehicle travel, vehicle maintenance and disposal of used vehicles. The environmental impacts of vehicle travel include exhaust emissions, dust emissions from tyre wear on road surfaces, emissions of refrigeration agents for vehicle air conditioning, noise and safety in terms of accidents. Pollutants from motorised vehicles include nitrogen oxides and particulate matter. These pollutants present a two-stage problem with primary and secondary air pollutants. Primary air pollutants include, carbon monoxide, nitric oxide, benzene and particulate matter European Environment Agency (EEA: 2012).

Secondary pollutants include nitrogen dioxide and ozone, which is formed by the effects of sunlight on volatile organic compounds (Pearce 2000). Each of these pollutants damages human health, for example particulate matter is dust emitted from exhausts and is usually measured by diameter and expressed as PM_{10} which is the level of particulate matter with a diameter of 10microns or less. Scientific evidence shows that high levels of PM_{10} can affect the human respiratory system, cause long term damage to the heart and lungs and is potentially carcinogenic (Pearce 2000).

These pollutants can adversely affect human health and the environment affecting ecology and destroying ecosystems. The OECD (2011) state, that global greenhouse gas (GHG) emissions reached an all-time high of 30.6 gigatonnes (Gt) in 2010. It is estimated that these emissions will continue to increase by approximately 50% by 2050 unless national governments implement prevention policies. To put the problem in context, these predicted increases equate to an atmospheric concentration of GHG's of an estimated 685 parts per million (ppm) CO2-equivalents by 2050, which is significantly greater than the concentration level of 450 ppm required to stabilise the climate at 2 degrees (2°C) global average temperature. The OECD (2011) and environmental experts warn that such high levels of GHG's could potentially increase the global average temperature by 3 to 6^{o}C higher than pre-industrial levels before the end of this century, leading to significant changes in precipitation patterns, melting glaciers and rising sea-levels, with "*catastrophic or irreversible outcomes for natural systems and society*" (OECD 2011).

There have been significant advances in car technology, such as catalytic converters and lead free petrol engines, which have led to the reduction of exhaust emissions. However the European Environment Agency (EEA: 2012) maintain that the continuing growth in vehicle use and vehicle km/year mean that efforts to reduce emissions from individual vehicles are in danger of being overtaken by increases in the volume of traffic. According to Tyler Miller & Spoolman (2011) the USA is a prime example of a car centred country. The country contains 4% of the world's population with an estimated one third of the world's private cars and commercial vehicles. The country has developed with dispersed cities and urban sprawl. Passenger vehicles are used for 98% of travel needs, with an estimated three quarters of the working population driving to work in single occupancy each day. These travel patterns mean that the USA is responsible for an estimated 43% of the world's total vehicle fuel consumption. Statistics released by the Department of Transport in the UK, indicate that the number of vehicles in the UK is increasing from an estimated 4 million in 1950 to 34 million in 2010, equating to an annual growth of 3.7%. The proportion of households with access to a motor vehicle has increased from 14 per cent in 1951 to 75 per cent in 2010. There is also evidence that the average annual mileage of four-wheeled cars is falling from an estimated 9,700 miles in 1995/97 to 8,430 in 2010 (Department of Transport 2012). According to the Department for Transport (DfT 2011), transport makes up 21% of all United Kingdom's domestic carbon emissions.

National governments are committed to reducing greenhouse gas emissions and one of the key target areas is reducing emissions from road vehicles. In order to do most transport policies need to implement traffic demand measures, which will encourage a modal shift away from the private car and towards greater use of public transport and non-motorised modes such as cycling and walking. In order for these policies to be effective Chatterjee & Venigalla (nd.:p.1) point out that the transportation planning and management of travel demand must have a thorough understanding of travel patterns and existing problems before carrying out policy changes. This requires detailed data on existing travel patterns, with traffic volumes and forecasts for predicted traffic volumes and pollution emissions from that traffic to be determined. Once the extent of the problem is realised only then can planners and policy makers implement strategic policies to address the issue. The remainder of this literature review will focus on travel demand management and specific examples of traffic demand management schemes.

2.3 Travel demand management (TDM)

Travel demand policies are implemented to reduce the negative aspects of vehicle travel. This section of the literature review will include an analysis of the definition of travel demand management with example of schemes implemented. It will also consider the effects of these schemes and assess whether these policies have been successful.

2.3.1 Definition of travel demand management

According to Zhou (2008) travel demand management programmes were first considered in the 1970's with respect to problems of air pollution and road congestion. Zhou (2008) suggests that TDM is a "*general term for strategies that result in more efficient use of transportation resources*" or a "*combination of various strategies that change travel behaviour"* with two main aims increasing the efficiency of transport systems and reducing congestion. According to Donna & Nelson (2000) Traffic demand management is the use of techniques, policies or strategies to decrease traffic demand in an area or to alter this demand within defined time or space parameters. This alteration is often with particular empathise on reducing the use and impact of private cars with low occupancy.

The term travel demand management (TDM) represents measures which aim at reducing car dependency and supports strategies that encourage the use of other alternative modes such as public transport and/or cycling and walking. TDM includes strategies that improve the transport options available to users, incentives that encourage travellers to use more efficient transport options, more accessible land use patterns, planning reforms and various support programs (Litman, 2003). A TDM measure seeks to manage the demand for travel using drive alone private cars, rather than catering for that demand, or managing the road system on which those cars travel. TDM's goal is to design and implement transport policies that modify trip maker behaviour, optimize the use of road space, and integrate operations of various transport modes, to improve transport safety and efficiency, minimize environmental impacts, and promote socioeconomic benefits.

TDM is aimed at reducing congestion and all the negative impacts associated with congestion on transport routes. According to Ison & Rye (2008) TDM measures aim to influence transport mode choice that people use, trip length, frequency of trips made and the route travelled. The European Environment Agency (EEA) (2012) point the problem of vehicle emissions can be dealt with through TDM and that this can be dealt with by local authorities who are best placed to assess the needs of their communities and the resources available. Potentially beneficial TDM schemes include improved public transport, park and ride schemes, traffic restrictions and land-use management.

There is evidence of a growing awareness among the general population of the problems associated with car travel. A travel survey conducted by the Department of Transport, found that 87 per cent of respondents believed that congestion was a serious problem for the country and over 77% believed that it was important to implement measures which would alleviate congestion. The survey noted that this view varied across social group and different areas. The main concerns regarding congestion were first that congested roads make it difficult to predict road journey times and it wastes time, especially with respect to businesses and logistics (DfT 2008). The study showed that people recognised that there was no easy solution to the complex urban problem and although were concerned about congestion in terms of its personal affect and its impact on the global environment, there was a general reluctance to change behaviour (DfT 2008).

In other words, TDM measures are aimed at influencing mode choice, trip length, the frequency of trips and the route taken. They can be applied to meet specific goals, namely to reduce congestion, reduced parking stalls, decrease property owner/manager maintenance costs on parking areas, create more commuting choices for the public, delay the need for new road construction, and to improve air quality or to reduce the reliance on specific source of energy.

The negative impacts of increasing vehicular use could be addressed by implementing suitable TDM measures. Potter (2008) argues that in the UK there is evidence that the average trip length is increasing by 0.15km per year, that there is a decline on 0.3% per year in vehicle occupancy rates and an increase of travel pattern shift towards car-based leisure travel. Statistics from the Department of Transport show that the UK road network accommodates on average over 650 trips per person by car every year, an estimated 4.4 billion annual passenger bus trips per and also accounts for two-thirds of freight moved in the country. Road traffic has grown by an estimated 84 per cent since 1980, equating to an increase from 172 to 318 billion vehicle miles. Most of these increases are attributed to an increase in the number of cars on the roads and increased car use, which accounts for an increase of 87 per cent since 1980, from 134 to 250 billion vehicle miles (DfT 2008). Potter (2008) suggests that the demand for transport is influenced by a number of factors that generate traffic. These factors include the total number of trips, the length of travel trip, mode used and the number of occupants in a vehicle. TDM focuses on encouraging a modal shift, traffic volumes and reducing congestion. TDM measures can take the form of land use, communication substitutes, traveller information systems, economic measures, administrative measures, parking management, traffic management, preferential treatment and public transport (OECD 2002).

2.3.2 Travel demand management (TDM) measures

TDM can provide wide range of benefits, which include not only reduction in traffic congestion, road and parking facility cost savings, better public transport options for non-drivers, consumer cost savings, traffic safety and reduced pollution emissions. Conventional transport planning tends to focus on a limited set of objectives, and so often overlooks some of these benefits. Hence, TDM strategies are sometimes tending to be undervalued. TDM planning requires more comprehensive evaluation that accounts for a wide range of options and impacts. Rather than selecting a single solution to a single problem, a TDM program usually involves a combination of complementary strategies that together achieve a variety of objectives.

There are a number of different types of travel demand measures, which can be categorised as follows; economic measures, land use information for travellers, substitution of communication for travel and/or administrative measures. Economic measures include fuel tax, road user charging and parking charges. Subsidising public transport could also be categorised as an economic measure. Land use measures include land use and transportation strategies such as car-free zones and park and ride facilities. Traveller information strategies include car sharing and providing travel information before a trip is undertaken. Internet shopping and using modern forms of communication such as tele-working instead of commuting to work is a form of TDM. Administrative measures include parking controls, pedestrianised zones and alternative work patterns, to reduce rush hour congestion (Ison & Rye 2008).

TDM measures may be implemented across a country, for example with fuel tax, or the measures may be implemented on an area basis for example parking control in a city. These measures can be used in short or long term, where long term measures mainly focus on land use patterns (Ison & Rye 2008).

2.3.2.1 Economic measures

One example of a TDM economic measure is taxation, which includes taxation on fuel, road user charges, road tolls and parking charges. Potter (2008) points out that taxation measures must be targeted at influencing decisions on mode of travel and the amount of travel. One effective TDM measure is fuel excise duty, which is added to the each litre of fuel purchased. In England the rate of tax differs for each type of available fuel, for example there is a considerable difference between unleaded petrol prices and diesel. In some European countries for example the Netherlands, there is a carbon and energy levy on fuel in addition to taxation. The benefits of this type of transport policy is that it makes people think about their journey and mode of transport, it provides a reasonable source of income for the Exchequer and it is relatively simple and easy to implement. Effectively this TDM measure means that the user pays for their chosen mode of transport. Potter (2008) argues that fuel duties have a positive effect on traffic generating factors such as modal choice, trip length, trip linking and vehicle occupancy rates. However Potter (2008) also points out that fuel taxation is a slow TDM measure and must be implemented consistently, with rises relative to the cost of public transport, in order to be effective.

Another example of economic TDM measures is parking control implemented by the city Council in Nottingham. The parking control strategy is part an integrated transport strategy in which the parking management strategy works incrementally to control and price parking across Nottingham. The strategy includes restraint, pricing and management of parking across the city. Restraint is implemented by limiting the number of parking spaces within the city, including limiting the car parking spaces allowed with new developments. Parking restraint is also implemented through on street parking controls and "*residents parking only"* permits in residential areas. This is linked with charging for on street parking in areas that are prone to congestion and where demand for parking is high. The council has also implemented a Workplace Parking Levy scheme, where employers must pay a fee for each parking space attached to their business. These measures are cushioned by management measures such as providing a park and ride scheme, information for employers with respect to parking allocation and management of that parking. The management measures also include a smart card access via controlled barriers to parking zones (Seisaku & Kiko 2004).

Congestion charging could be considered an economic TDM tool. According to the International Transport Forum (2010) congestion charging is designed so that vehicle drivers pay a percentage of the true cost of the journey undertaken, with the ultimate aim of suppressing demand. Congestion charging is a means of addressing the difference between the personal journeys and essential journeys. Gomez- Ibanez & Small (1994) maintain that road congestion charging can reduce the volume of traffic on roads, with corresponding improvements to travel time and a reduction in air pollutants. It can also result in faster bus journey times with improved frequency and reliability of services. There should be an increase in passenger revenue as travellers move from car to public transport. Congestion charging was introduced into Central London in 2003 with the specific aim of reducing the level of congestion, to improve journey times and to make the distribution of goods and services in the capital more efficient (TfL 2008). There were mixed opinions on the scheme before its introduction to the City, with residents largely in favour of the scheme and non-resident route users against road charging. Ison (2004) suggests that prior to the congestion charge, a survey of Londoners indicated that approximately 90% felt that there was too much traffic in central London and of those surveyed 40% were in favour of congestion charging. A follow-up survey after implementation of the congestion charging found that support among residents remained strong and many perceived an improvement to air quality, a better living environment and reduced congestion. On the other hand, an estimated 59% of drivers using the route but not living in the charging zone believed that they were being penalised by the scheme (DfT 2010).

This economic TDM measure was successful in improving the local environment. Studies carried out by Transport for London (TfL 2005) found that the congestion-charging scheme reduced the volume of cars travelling through London by 33%, with 11% fewer lorries and vans. There was a 17% increase in taxis and a 23% increase in buses. These changes in the volume of traffic resulted in a reduction in congestion with travel times reduced from 2.3min/km to 1.6min/km. A second study carried out found that major pollutants due to vehicle emissions decreased, with a decrease of 6% in nitrogen oxides and a 7% reduction of particulate matter (DfT 2010). Statistics from the London scheme indicate bus passenger numbers have increased on average by 6% since the introduction of congestion charging, with cyclists up by 12% (DfT 2010). The Environmental Research Group carried out an analysis of vehicle emissions of these reduced flows, using a road-traffic emissions model. The study found that in the first year of operation total NOX emissions in the charging zone fell by 12.0% with a corresponding increase of 1.5% on the inner ring road. PM10 emissions have reduced by an estimated 11.9% in the charging zone and by 1.4% on the inner ring road. These decreased emissions of NOX and PM10 is attributed to an increase in vehicle speed and a reduction in the number of vehicles. The charging scheme has reduced the number of vehicle km driven within central London, which has increased bus use and the number of buses travelling in the area. It was anticipated that this increase in bus use would lead to greater exhaust emissions however these impacts were minimised by the introduction of particle traps in the buses and also by using new modern vehicles (Beevers & Carslaw 2004).

2.3.2.2 Land use measures

Land use planning is a long term TDM measure which can be used to reduce the need to travel, reduce the length of trips taken and increase the use of public transport, cycling and walking (OECD 2002). Land use planning is implemented through national planning policies such as Planning Policy Statement PPS1. PPS1 focuses on sustainable development and the implementation of land use measures, which "*provide improved access for all to jobs, health, education, shops, leisure and community facilities, open space, sport and recreation, by ensuring that new development is located where everyone can access services or facilities on foot, bicycle or public transport rather than having to rely on access by car, while recognising that this may be more difficult in rural areas*." (Office of Deputy Prime Minister 2005). This shows a clear government policy in favour of reducing reliance on the private car and promoting more sustainable modes of transport. At a local level, local authority planning offices are responsible for approving plans for new developments or changing uses of existing developments (OECD 2002). A study carried out by the Department for Transportation (DfT) into the relationship between population density and travel demand found that higher population densities increase the opportunities for development of personal contact and these types of developments reduce the average distances travelled for services and employment. The study also showed that higher density development improved the potential viability of public transport. However OECD (2002) point out that land use planning alone is not an effective TDM tool. OECD (2002) also point out that the disadvantages of land use planning include conflicts of interests between public policy and private development and obtaining a compromise between high land costs and low travel costs.

A good example of land use planning is the Greenwich Millennium Village in London. This sustainable development was constructed on derelict contaminated land in Greenwich London. The project was conceived, designed and constructed on the principles of sustainable development, in accordance with Planning Policy statement PPS1. The development provides homes for over 7500 residents and employment in the area for an estimated 6,500 people. The development has been designed to provide access to all necessary services such as shops, schools, health services within a reasonable distance for the residents reducing the need to travel by car. The development also gives greater priority to non-motorised forms of transport such as pedestrians and cyclists over cars. The designers also took account of integrated transport and there is a dedicated bus service to rail transport links. This scheme proves that it is possible to implement travel demand measures that reduce the need to travel and still create a pleasant environment where communities can thrive socially, economically and without damaging the environment OECD (2002).

2.3.2.3 Communication substitutes

Information and communication technology (ICT) is increasingly being used in the modern world and though it is difficult for transport planners to specifically implement this as a TDM measure, it has the potential to reduce travel demand by reducing the vehicles miles travelled, through trip elimination or replacement. These measures can be divided into transport telematics such as smart cars, satellite navigation systems, variable message signs and traffic information; teleworking, teleconferencing, internet shopping and services and distance learning (OECD 2002).

Table 2.3 shows examples of TDM measures and areas where these measures can be used to improve the transport system in the UK and Figure 2.13 depicts the conceptual framework for the TDM measures adopted from Garling et al., (2002). These measures include physical measures such as bus lanes, regulatory policies and other public transport measures. The investigations of using bus lanes and speed reduction measures on TDM have been studied widely in the UK and other countries.

Table 2.3: Travel demand management measures

TDM Measures	Examples
Physical change measures	improving public transport
	improving infrastructure for walking and cycling
	park & ride schemes

	land use planning to encourage shorter travel times
	bus lanes
	technical changes to make cars more energy-efficient
Regulatory policies	prohibiting car traffic in city centres
	parking control
	decreasing speed limits
Pricing policies	taxation of cars and fuel
	road or congestion pricing
	kilometre charging
	decreasing costs for public transport
Information and education measures	individualized marketing
	public information campaigns
	feedback about consequences of behaviour
	social modelling

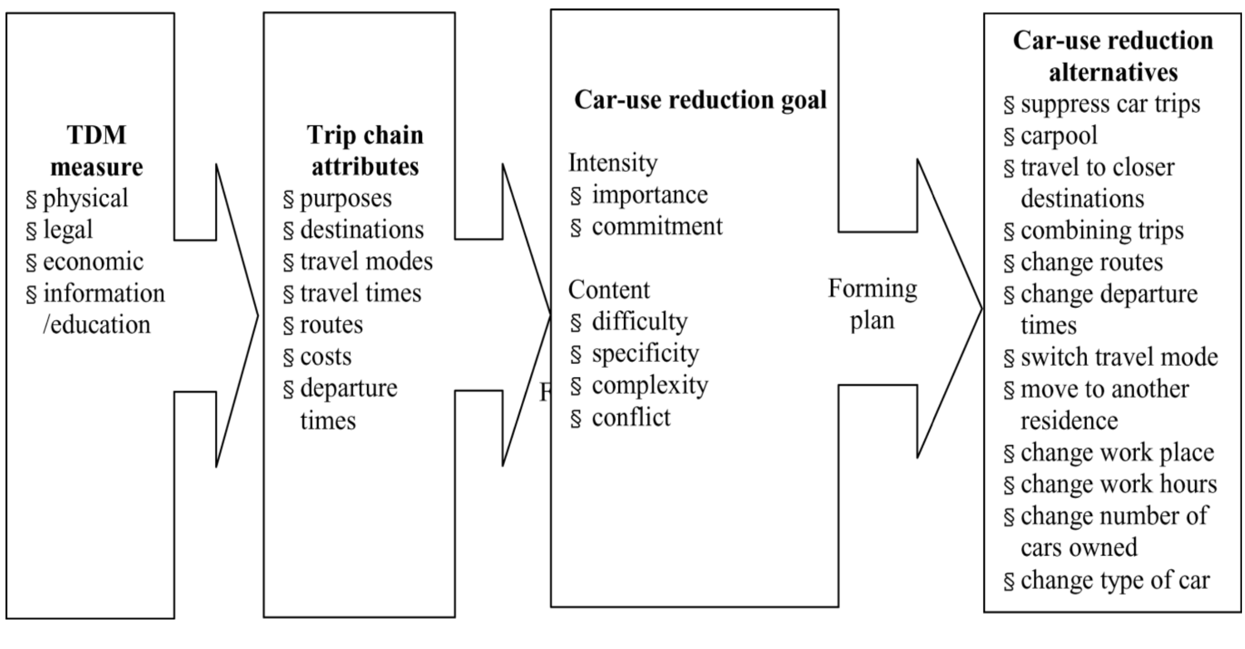


Figure 2.13: The conceptual framework (adopted from Garling et al., 2002)

The VTPI Online TDM Encyclopaedia (www.vtpi.org/tdm) is designed to help transportation

Table 2.4: TDM strategies included in the online TDM Encyclopedia

Improved transport options	Incentives to shift mode	Land use management	Policy and planning reforms	Support programs
Address security concerns	Bicycle and pedestrian encouragement	Car-free districts	Car-free planning	Access management
Alternative work schedules	Congestion pricing	Clustered land use	Comprehensive transportation market reforms	Campus transportation management
Bicycle improvements	Distance-based pricing	Location efficient development	Institutional reforms	Data collection and surveys
Bike/transit integration	Commuter financial incentives	New urbanism	Least cost planning	Commute trip reduction
Car sharing	Fuel tax increases	Parking management	Regulatory reform	Intelligent transportation systems
Guaranteed ride home	High occupant vehicle (HOV) priority	Smart growth		Freight transportation management
Park and ride	Pay-as-you-drive insurance	Transit oriented development (TOD)		School trip management
Pedestrian improvements	Parking pricing	Street reclaiming		Special event management
Ridesharing	Road pricing			
Shuttle services	Vehicle use restrictions			
Taxi service improvements				
Tele-work				
Traffic calming				
Transit improvements				
universal design				

professionals identify, plan, evaluate and implement TDM programs. The website provides detailed information about different TDM measures and their impacts. This information has been reviewed by experts, and is regularly expanded and updated. Table 2.4 lists TDM strategies that are included.

Each strategy in the above mentioned table is rated on a seven-point scale according to various criteria, including its travel impacts, its ability to help achieve different objectives, its equity impacts, and appropriateness in different geographic and organizational conditions.

The objectives considered in the Encyclopaedia are listed below.

- Congestion reduction
- Road and parking savings
- Consumer savings
- Transport choice

- Road safety
- Environmental protection
- Efficient land use
- Community liveability

Smith, 2008 suggested many transport demand management measures which are summarised in Table 2.5. Many of these schemes require organisation, monitoring and control, which are relatively straightforward electronic tasks, requiring mere development of existing technologies and opportunistic use of newly developed techniques. The original intended uses may be far removed from transport, but parasitic opportunities will arise. The use of technology, for example, to enforce speed limits and hence increase capacity, to monitor and collect payments for road-charging schemes, to provide better real-time information for public transport is already in place and is relatively cheap. Improved technologies will undoubtedly emerge, and so technology will not be a barrier to the implementation of transport demand management schemes.

Table 2.5: Examples of transport demand management strategies (Hensher and Button, 2003)

Improve transportation options	Incentives to reduce driving	Parking and land-use management	Policy reforms and programmes
Alternative work schedules	Walking and cycling encouragement	Bicycle parking	Access management
Bicycle improvements	Commuter financial incentives	Car-free districts and pedestrianised streets	Campus transport
Bike/train transit integration	Congestion pricing	Clustered land use	Car-free planning
Car sharing	Distance-based pricing	Location-efficient development	Commute trip reduction programmes
Flex time	Fuel taxes	New urbanism	Comprehensive market reforms
Guaranteed ride home	High-occupancy vehicle priority	parking management	Context-sensitive design
Individual actions for efficient transport	Parking pricing	Parking solutions	Freight transport management
Park and ride	Pay-as-you-drive vehicle insurance	Parking evaluation	Institutional reforms
Pedestrian improvements	Road pricing	Shared parking	Least-cost planning
Ride sharing	Speed reductions	Smart growth planning and policy reforms	Regulatory reform
Shuttle services	Street reclaiming	Transit-oriented development	School transport management
Small-wheeled transport	Vehicle-use restrictions		Special event management
Taxi service improvements			TDM marketing
Tele work			Tourist transport management
Traffic calming			Transport management associations
Transit improvements			Universal design

TDM measures may also be classified in terms of those which discourage car use which are termed as Push measures and those that encourage the use of alternative transportation modes termed as pull measures. Table 2.6 presents many of these measures. They are listed on a continuum from primarily push measures to primarily pull measures. Stradling et al. (2000) surveyed English drivers providing them a list of pull and push measures that overlapped substantially. Conducting a factor analysis on respondents rating of effectiveness of these measures, he extracted two factors that were perfectly matching with push pull distinction. The exception was ‘public information campaigns about negative effects of car use’ which respondents grouped together with other push measures.

Table 2.6: TDM measures varying from Push to Pull measures (Garling et al.2002)

Taxation of cars and fuel
Closure of city centres for car traffic
Road pricing
Parking control
Decreasing speed limits
Avoiding major new roads infrastructure
Teleworking
Land use planning encouraging shorter travel distances
Traffic management reallocation space between modes and vehicles (Bus Lane etc)
Park and ride schemes
Improved public transport
Improved infrastructure for walking and biking
Public information campaigns about negative effects of driving
Social modelling

TDM is sometimes criticized as being harmful to consumers and unfair because it forces people with lower incomes to reduce driving and shift to ‘inferior’ transportation modes (Green, 1995). This is not necessarily true. Most TDM strategies that directly affect consumers rely on positive incentives, as illustrated in Table 2.7. The strategies categorized as ‘Positive Incentives’ improve travel choices and provide rewards for reduced driving. With such strategies, motorists who continue their current travel patterns are no worse off, but those who reduce their mileage must be better off overall, or they would not change. These direct benefits occur in addition to indirect consumer benefits, such as reduced congestion, tax savings, increased road safety and environmental protection. As a result, even people who expect to continue to drive have reasons to support TDM, if it is a cost effective way to reduce traffic problems. Table 2.7 actually exaggerates the negative impact. For example, pricing strategies are generally considered negative incentives, but their ultimate consumer impacts depend on how revenues are used.

Table 2.7: TDM strategies categorized by their direct consumer impacts

Positive incentives	Mixed	Negative incentives
Alternative work schedules	Access management	Fuel tax increases
Bike/transit integration	Car free planning	Parking pricing
Car sharing	Traffic calming	Vehicle use
Commuter financial	HOV preference	restrictions
incentives (most)	Parking management	Road pricing
Distance-based insurance	Comprehensive	
and registration fees	market reforms	
Flexible parking requirements	Smart growth	
Guaranteed ride home		
Improved personal security		
Location efficient development		
Park and ride		
Pedestrian and cycling		
improvements		
Ridesharing		
School trip management		
Shuttle services		
Smart growth		
Street reclaiming		
Taxi service improvements		
TDM marketing		
Tele work		
Transit improvements		
Transit oriented development		

Two problems can be identified when assessing the impacts of TDM measures: Firstly, environmental impacts of such measures have not always been considered as one of their consequences. For example speed calming measures have mostly been assessed based on speed reduction and accidents prevention along the roads, while environmental impacts of these policies are not considered. Secondly, when assessing environmental impacts of such TDM measures, a lot of aggregation and average values in the data are used for example average stopping times for buses along the bus corridors, average delays, or estimated values of these variables from some models. Conventionally, these measures are usually assessed using various modelling and analysis techniques (for example travel demand forecasting, simulation modelling etc.) and in most cases the performance data relevant for input to these models is used whereas in this study, the driving cycle data and analysis have been used to obtain more accurate assessment of the impacts of TDM measures in Edinburgh and Abu Dhabi cities.

2.3.3 Travel demand measures: Bus priority lanes

The first dedicated bus corridor was opened in the UK in 1971, in Runcorn; it had an elevated platform which went into a shopping centre. Since that time there have been numerous bus priority schemes all aiming to protect buses from road congestion and make public transport more attractive to passengers. There have been guided bus systems implemented in Bradford, Crawley, Leeds, Cambridgeshire, Kent and Luton-Dunstable. Cambridgeshire has built the longest guided bus system at 25 km long, the Luton-Dunstable system will be capable of operating on both a track and the public roads, Kent operates a non-guided bus system, opened in 2006, with half of the routes operating on space dedicated to the bus system (Deng & Nelson, 2011). These schemes differ from a conventional bus system in that they have, for a significant part of their operation, a dedicated space away from other private traffic. The mass transit term is in reference to a public transport scheme that is a large scale system which tends to serve a city. These mass transit schemes have fast running speeds, they have the capacity to carry a large number of passengers and they generally have a right of way over other transport (Deng & Nelson, 2011).

Since the deregulation of public transport services, the transport requirements of the public have been met by a combination of commercially based public transport, local authorities, and some charities that meet the requirements of certain groups with high specific needs (Brake & Nelson, 2007). The exact proportion of this mix will vary by area, particularly depending on whether the area is comprised of rurally communities or if it is a city.

Most public transport journeys made in the UK by bus use a fixed route service which is registered with the UK Traffic Commissioners, which means that exact routes and the frequency of the service is guaranteed. Although the local or statutory authorities do provide a number of bus services that are not registered. These are, for example, transport for education, care services, social and non-emergency patient transport (Brake & Nelson, 2007).

White (1995) suggests that bus lanes are TDM measures that give buses priority over other modes of traffic in the same road space. King & Bod (1997) suggest that the efficiency of bus priority measures is dictated by the weakest links along the route and this is compounded by the fact that these schemes try to give buses priority whilst maintaining existing traffic flows. White (1995) states that there is a case for giving buses priority over other forms of traffic, this would make the form of transport more attractive to users and that in "*conditions of scarce road space, giving priority to the most efficient users of that space (buses) may reduce total travel time within the network*"(White 1995). There is evidence that in areas where buses do not have priority up to a third of the bus journey can be spent stationary. Bus priority measures can include bus lanes, priority at traffic signals and dedicated road space. Case studies show that if bus priority measures are carefully planned and implemented over whole routes that this can significantly increase the number of passengers using buses. Two typical examples are the Edinburgh Greenways Scheme and the London Bus Initiative.

2.3.3.1 Edinburgh greenways scheme:

Edinburgh has suffered from severe traffic congestion since the 1980's, with a much higher rate of private car ownership than the rest of the UK, with an increase in car ownership of 37% compared to a national average of 19%. This level of car ownership resulted in high pedestrian and cyclists accidents rates, environmental impacts such as noise, air pollution, congestion, and slow travel times with corresponding impacts on business and quality of life. This high percentage of private cars has also affected public transport, effectively reducing the level of service to that of the private car, with the perceived benefits of private car travel. The City Council introduced the bus priority "Greenways" scheme, with the objective of "*restoring the balance of car use and public transport*." The priority scheme aims to improve the reliability and speed of bus services in the city, cutting bus journey times by 10% in the hope that this would increase modal shift from private to public transport (Policy note nd.:p1). The council also wished to reduce environmental impacts in the city due to private car use. Greenways were introduced in 1997 and involved the phased introduction of 26 kilometres of bus lanes on five routes within the city. These bus priority measures increased bus priority measures in the city by three-fold. Greenways are different from conventional bus lanes as they require strict enforcement and traffic calming on side streets. These schemes are planned to incorporate cyclist and pedestrian improvements, with priority given to buses and non-motorised travel. The greenway operates through the day, unlike conventional bus lanes, which generally operate at peak times. Yellow road markings are replaced with red lines, which are policed using traffic wardens. The greenways scheme also provides a better standard of bus shelter and information system than is associated with conventional bus lanes. These differences also equate to a more expensive option than conventional bus lanes, with greenways costing an estimated £500,000 per kilometre and bus lanes costing an estimated £100k /km (Scottish Government 2000). The Scottish Government funded a study into the effectiveness of the greenways. This study revealed that the Greenway had improved the reliability of bus services along the A8 corridor. It also concluded that Greenways provide a greater level of insulation from traffic congestion for businesses fronting major roads, when compared to conventional bus priority measures. This is also evidence as there are an increasing number of passengers using public transport along the A8 route. The study shows that the A8 greenway has improved safety for pedestrians and cyclists. Bus drivers were in favour of the greenways; however emergency service drivers had mixed views. The study found that in areas where a Greenway is located bus journey times tend to remain constant whereas car journey times increase due to congestion. Taxis are permitted to use the Greenways and therefore their travel times reflected those of the buses. In areas along the route where a Greenway could not be implemented due to restricted space, it was found that bus times were similar to those of private cars. The implementation of Greenways has made bus services more reliable especially in am and pm peak times. The Greenways appear to have reversed the falling levels of public transport usage in parts of the city, although the figures. The data collected in the study indicates that there are a greater number of people using conventional bus lanes coming into the city and a greater percentage of passengers using Greenways when travelling out of the city in the afternoon peak. The study also revealed that the effectiveness of Greenways is largely dependent on policing and enforcement. It was revealed that in areas where there was no retail frontage, the performance of Greenways was similar to conventional bus priority measures. However, Greenways performed better than conventional bus lanes in areas where there was retail frontage.

There is however, evidence that these Greenways are causing delays to non-priority traffic and that Greenways require significantly more policing than conventional bus lanes. Some business owners believe that the Greenway schemes have led to a reduction in overall business with corresponding decreases in annual turnover (Scottish Government 2000).

2.3.3.2 London bus initiative schemes

The London Bus Initiative phase 1 and 2 were implemented since year 2000 supported by strong funding from the government. Phase 1 included routes 220, 270 and 280 in the Borough, which overlapped with each other and created a study corridor between Putney Bridge, SW15 (Thamesfield) and Tooting, SW17 (Graveney) and incorporating Putney Bridge Road, part of the Wandsworth one-way System, Garratt Lane, Mitcham Road, SW15, SW17/18 (Fairfield, Southfields, Earlsfield, Tooting and Graveney) and the loop around St George's Hospital of Fountain Road, Blackshaw Road and Tooting High Street SW17 (Tooting). Changes to these routes were proposed by JMP Consultants and approved (Paper No. 02-14) by the executive on 14th January 2002. Phase 2 of the London Bus Initiative included ten routes partly within the Borough were involved in this phase.

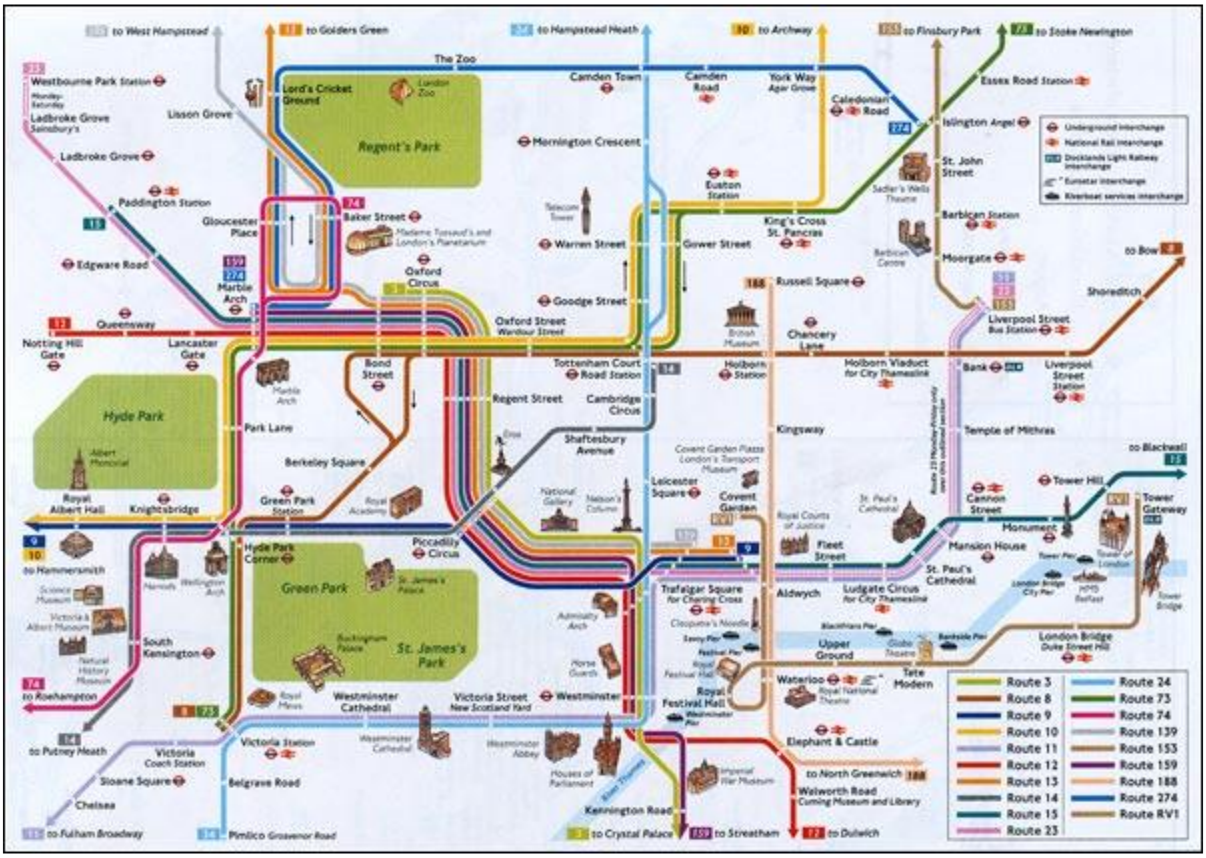


Figure 2.14: Key bus routes in central London (Source: Google Maps)

UK Department for Transport (DfT) publication on bus priority (2010b) provides information about many other bus lane scheme initiatives in the UK. There are other similar efforts done in the West midlands using the scheme called West Midlands showcase in 1997, Leeds city centre in 1997 and year 2000, Oxford historic city since 1970, and more studies in 1997 and

1999. The West Bromwich town centre implemented Bus lane scheme like the ones mentioned above in 2001 and 2002. It has been claimed that very positive impacts of bus lanes on traffic in a number of cities in the UK has been achieved.

(Hodges 2007) points out that there are 8000 London buses carrying over 6 million people on 700 routes, making it one of the most comprehensive bus services in the world. For the past decade, a key objective of the Mayors transport policy has been to improve the management of the bus network through bus lane priority schemes, such as the London Bus Initiative. The scheme led to a partnership of all the 33 London Boroughs with Transport for London with the objective of delivering the highway infrastructure needed to support London's existing and planned bus services. The London Bus Initiative Phase 1 (LBI1) was established in 2000 as a 3 year fixed term bus- improvement initiative supported by a £60million grant from the government. The aim was to make bus travel more attractive. The initiative consisted of identifying twenty-seven high frequency bus routes across London, called Bus Plus routes. These routes were selected for improvement works because they served areas where improvements could be made to integrated transport services or where a more reliable bus service was needed to aid regeneration of an area. The partnership took a year to set up and produce a detailed plan of work, followed by two years of design, consultation and detailing. The approach was to consider the whole route and not just sections of a bus route A key objective of the London Bus Initiative partnership was "*to improve compliance with bus priority measures along the entire length of all London Bus Initiative routes* ", with co-operation from the City Police and the Metropolitan Police. The ultimate objective of these works was to improve the reliability of bus services, to protect bus services from congestion and by improving the services encourage modal shift from the car to public transport.

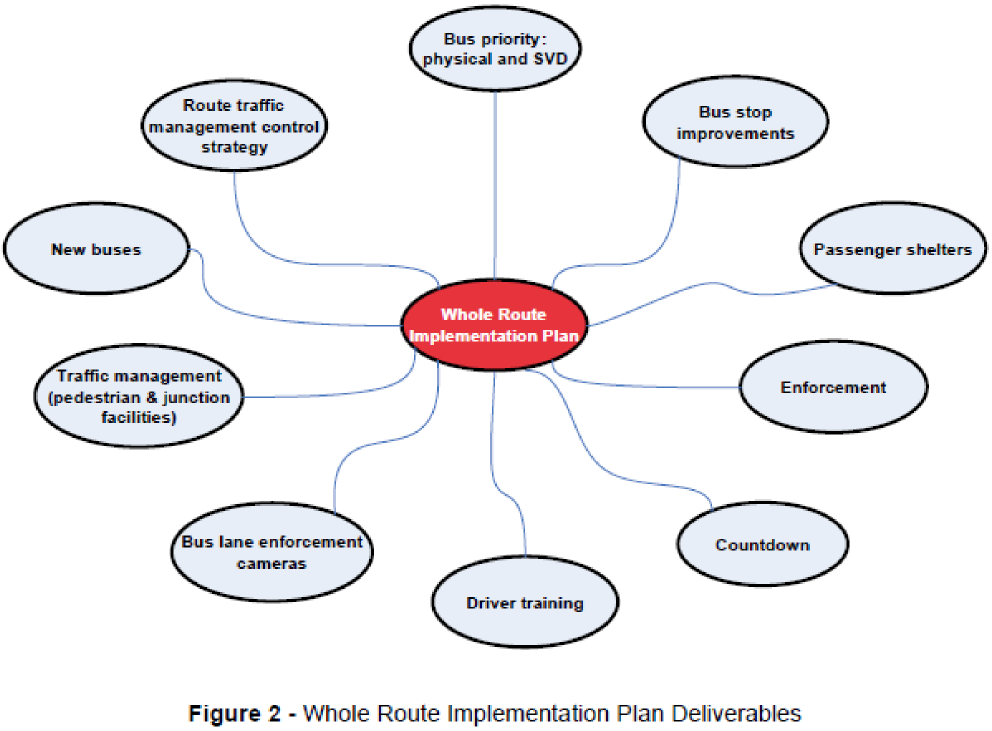


Figure 2.15: (Hodges 2007) Whole route implementation plan

Each route was assessed in terms of ten main elements, such as enforcement, pedestrian facilities and bus stop improvements; in effect the team agreed that in order to encourage people onto London Buses the whole system needed to be addressed. The ten elements considered are shown in figure 2.14 above. The routes were categorised as quality whole routes and whole routes, with two sub-categories of quality, high priority and priority. The scheme included a careful study of the existing road network and bus performance along the chosen routes. According to Hodges (2007) a range of measures were implemented as part of the scheme including 100 new bus lanes, 50 new pedestrian crossings, improvements to over 300 signalised junctions to give bus priority over other traffic. Enforcement of the bus priorities was achieved by using roadside CCTV and on bus cameras, as well of enforcement officers in every Borough. The scheme also improved the bus fleet with enhanced passenger information, better training for bus drivers and cleaner more efficient bus vehicles.

Hodges (2007) points out that this co-operation between the authorities and the bus companies helped make the scheme a success. The key outcomes of the initiative include an increase in bus patronage with an increase of 22% more passengers over a three-year period.

The scheme has also improved bus reliability with waiting times reduced by 9% and greater customer satisfaction.

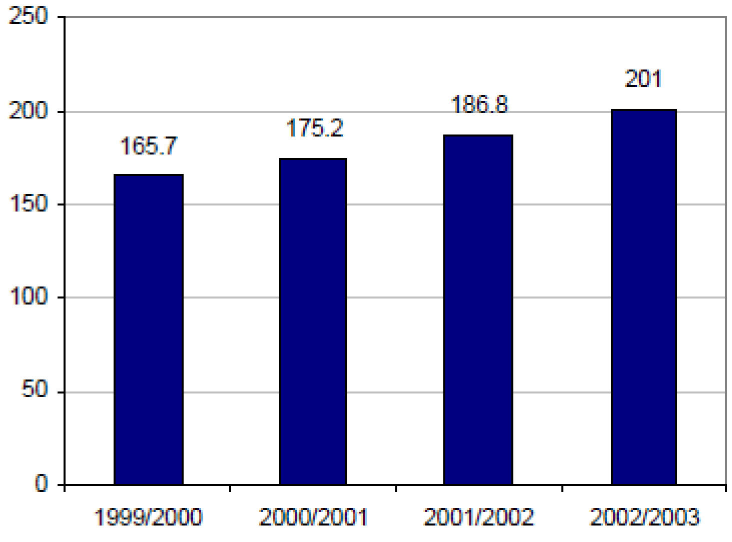


Figure 2.16: (Hodges 2007) Annual patronage London bus initiative routes

This scheme deployed parking attendants to enforce the bus lane regulations and issue Penalty Charges to bus lane violators. The bus lanes are monitored using cameras with specially trained staff to enforce the regulations (Bexley 2002). The London Bus initiative has contributed to the increase in bus patronage in London, with an increase of 40% in patronage between 1999 and 2007. These increases are attributed to expanded network, improved reliability and provision of new buses (Hodges 2007).

2.3.3.3 Bus lanes and their assessment

According to Collins English Dictionary & Thesaurus (2006) a bus lane is a part of the road which is intended to be used only by buses. Many strategies have been put in place in different areas to ensure the effectiveness of the bus lanes. These schemes were conceived, studied, and implemented in the UK cities, just to name a few; Edinburgh, London, and West Midlands. According to Deng & Nelson (2011) these schemes differ from a conventional bus system in that they have, for a significant part of their operation, a dedicated space away from other private traffic. The mass transit term is in reference to a public transport scheme that is a large scale system which tends to serve a city. These mass transit schemes have fast running speeds, they have the capacity to carry a large number of passengers and they generally have a right of way over other transport. The schemes have successful milestones, problems, and hence the continued need to improve them is highly considered.

Before and after monitoring of bus performance and patronage results (DfT: 2010) suggest that bus lanes or greenways have been successful in improving bus patronage and improving bus performance. Local people and bus operators are often involved in the exercise, and lessons are learnt from the past. In most cases, suggestions to improve or amend some aspects of the schemes are reached together with the city authorities.

Accessibility can be defined by Brake & Nelson (2007) as "the ease with which an individual can access services and facilities that he or she needs or desires". This is seen as a vital means of achieving social inclusion, sustainable communities and social justice (Brake & Nelson, 2007).

One method of increasing accessibility is in the use of elevated platforms or very low floors on buses. Not only does this increase speed of loading and unloading, it always enables easier access to people with mobility problems, although the majority of buses can be lowered if necessary for people with obvious needs or at request (Deng & Nelson, 2011).

Bus mass transit schemes are shown to be generally cheaper to implement than equivalent rail or tram services (Deng & Nelson, 2011).

Non-traditional bus services can improve on the efficiency involved. For instance having non or semi fixed route on the bus system, that respond to local user demand in comparison to a fixed service can be used. This could incorporate different fares for standard users and users with additional requirements such as being collected and / or deposited at a specific location. The use of services whose priority is different can be utilised, for instance, using post vans or school children delivery services for buses when the demand is required (Mulley & Nelson, 2009).

Reports are used in the evaluation, monitoring, and performance of the scheme by traffic counts, journey time measurements, casualties and accidents reports, registered local complaints, results from local gallery meetings and workshops. In most cases these reports claim major benefits from bus lane schemes.

Buses are often viewed as being unreliable, slow and a poor quality form of transport, although the rapid transit bus schemes have improved this image with their improved performance (Deng & Nelson, 2011). The use of separate bus lanes will increase the speed of the bus although it obviously will have some effect on the flow of other vehicles, especially at junctions.

Whether the use of mass transit bus schemes increases of decreases the value of the land and properties that have access points and are along the route is under debate by experts. It is perceived by the general public to be a less permanent transport investment than, for instance, a rail service, therefore limiting the impact on property prices. There is some evidence to suggest that this type of bus scheme increases properties prices, especially for commercial land use such as offices and for high density residential properties. Although residential properties close to large access points, such as bus stations show some indicators of decreased property price (Deng & Nelson, 2011).

Basso et al. (2011) analysed urban congestion management policies through numerical analysis of a simple model that: allowed users to choose between car, bus or an outside option (biking); consider congestion interactions between cars and buses; and allow for optimization of frequency, vehicle size, spacing between stops and percentage of capacity to be dedicated to bus lanes. He compared resulting service levels, social welfare and consumer surplus for a number of different policies and found that dedicated bus lanes are a better stand-alone policy than transit subsidization or congestion pricing. He further argued that from a policy that assigns part of road capacity to dedicated bus lanes, one expects the bus speed to increase considerably, given that buses are no longer trapped in car congestion. Car speed may increase as well, because cars may now avoid conflict with buses (including bus stop operations), but decreased capacity for cars may have the opposite effect. He found that indeed buses can go more than three times faster, while cars decrease their speed by two km/hour and this large change in speeds induces a sizeable increase in bus frequency (about70%) while decreasing the bus size from 100 to 80 people. It is interesting to note that the increase in frequency does not require an increase in bus fleet; the fleet needed is actually 80% smaller than in the base case. Higher bus speeds also induce a larger separation between bus stops, something that neither transit subsidies nor congestion pricing made. Overall, dedicated bus lanes induce sizeable changes in service levels, something that under mixed traffic conditions do not happen. As a result of all these changes, bus demand increases importantly with respect to mixed- traffic conditions. Hence implementing dedicated bus lanes seems to be a policy that, from a social welfare point of view, can improve any existing situation. Mohring (1979) argued that bus speed was one of the most important attributes of the system and that as such, it should be one the central objectives of planners, if they want to increase bus patronage. This is why he considered that dedicating lanes exclusively to bus traffic can be a quite successful policy. Furthermore, he argued that dedicated bus lanes may be a tool equivalent to congestion pricing in achieving a change in modal split.

Pogun and Satir (1986) evaluated alternative bus scheduling policies for an exclusive bus lane and found that dispatching more buses into the lane without making route modifications will decrease the efficiency of operations through more convoying. Thus, the dominant factor in setting a bus scheduling policy is the route to be followed. Among the route policies developed, RING policy achieved a 22.5% increase in the number of boarded passengers using the same number of buses. Thus, this policy was found desirable to implement if the Transportation Department of Ankara Municipality is not willing to allocate more buses to the exclusive bus lane. If, however, the objective is to maximize the number of passengers carried during the morning peak hours within the bus allocation constraints of the Transportation Department, then SERI route policy provides a 24.4% increase in the number of passengers served at the expense of increasing the number of buses operating by 21%. Thus, the changes in the operating policy largely depend on the priorities of the transportation department. However, it is evident that any change on the current policy should incorporate new ring and express services. The variance of passenger demand during morning peak hours was found to have no significant effect on the performance of scheduling policies developed as long as the same mean demand value is used for various statistical distributions. This is an indication for the degree of saturation of the passenger movements in the lane. Thus, the construction of a metro on the east-west axis of Ankara remains to be the only viable alternative in absorbing the ever-growing passenger demand.

Dahlgren (1998) developed a model to calculate these benefits for four alternatives: add a high occupancy vehicle lane, add a general purpose lane, convert an existing lane to a high occupancy vehicle lane, and do nothing. The model took into account the initial conditions, the dynamic nature of the travel time differential between the high occupancy vehicle lane and other lanes, and the uncertainty regarding the extent to which people will shift modes. It combined queuing theory and mode choice theory and provides a robust method for comparing alternatives using a small amount of easily observed data. Application of the model in typical situations showed that with initial delays on the order of 15 min or more, adding a high occupancy vehicle lane would provide substantial reductions in delay and some reduction in emissions. However, in a wide range of such situations, adding a general purpose lane would be even more effective. Only if the initial delay is long and the initial proportion of high occupancy vehicles falls in a rather narrow range, would an added high occupancy vehicle lane be more effective. The proportion of high occupancy vehicles must be such that it allows good utilization of the high occupancy vehicle lane while maintaining a sufficient travel time differential to motivate a shift to buses or carpools. They found out that adding a high occupancy vehicle lane to a three lane freeway would be more effective than adding a general purpose lane only if the initial maximum delay is on the order of 35 min or more and the proportion of high occupancy vehicles is on the order of 20%. Federal policies encourage construction of high occupancy vehicle lanes and restrict funding for general purpose lanes in areas that have not attained air quality standards. The findings of this research suggest a need to reconsider these policies.

Mannering and Hamed (1990) identified key weaknesses in the commonly accepted methods and criteria upon which HOV lane effectiveness is measured. According to them, these weaknesses arise from two sources; (1) the use of inappropriate measures of effectiveness, and (2) the use of analysis procedures that do not account for the full range of traffic system impacts. To address these weaknesses, a theoretically appropriate measure of HOV lane effectiveness was used, based on consumer welfare theory, and applicability of this measure in a dynamic traffic equilibrium model was demonstrated. Admittedly, the application of this method, as presented in this paper, is exploratory in nature, since the measure commuter welfare included only travel time, operating costs, and route and departure time changes, and did not explicitly account for mode choice or trip generation. Nevertheless, they presented a very important demonstration of methodology that can be used to draw three important conclusions. First, the passengers-per-lane measure of effectiveness has no theoretical basis and can produce contradictory and meaningless results. Second, the effectiveness of an HOV lane policy is very much dependent on a complex interaction among vehicle occupancy levels, overall traffic volumes, the extent of high occupancy vehicles usage, and the number of designated HOV lanes. Third, and most importantly, in light of the simulations undertaken that there is clear justification for taking a closer and more rigorous look at current HOV lane policy.

2.4 Traffic calming measures

This is another transport policy which is implemented to reduce the speed of traffic in a defined area. It is implemented using cushions, barrows, chicanes, signing, and traffic camera. In addition speed reduction schemes are implemented using special training to drivers and road users, dedicated campaigns and children education in schools e.g. the West Midlands Casualty Reduction Scheme. The scheme is supported and regularly improved by involving all stakeholders in the concerned area.

Traffic calming measures have been implemented in many cities and towns in the UK since the 1930's. Hard measures have been added to many streets in virtually every town in the UK, particularly when a way could be seen as being a "rat run". Examples in Aberdeen include road humps, bus lanes, chicanes and low speed limits. Traffic calming is used to reduce traffic accidents, have some positive environmental effects and encourage the traffic to proceed at a suitable speed for the road. There are a variety of "hard" and "soft" traffic calming measures that can be used to obtain these goals. "Hard" measures include building structures within the road to reduce the overall road speed for all or all motorised road users. These include road humps, rumble strips, road narrowing, no car lanes and traffic islands. Another method is reducing the speed limit, although additional measures, such as previously mentioned, may be needed if motorists perceive the speed limit to be too low for the road conditions. "Soft" traffic calming measures, can also be referred to as "smart" measures, can be used to reduce the speed of private vehicles while ensuring public transport, bicycles and taxis are not disrupted or are positively affected. These can be described as "more physiological than engineering" (Nelson, 2008).

2.4.1 Definition of traffic calming

Traffic calming is defined as measures "*concerned with reducing the adverse impact of motor vehicles on built up areas. This usually involves reducing vehicle speeds, providing more space for pedestrians and cyclists, and improving the local environment*" (Harvey nd.:section 3.0).

Traffic calming can be used, alongside other measures such as Park and Ride, road user charging and encouraging more environmentally friendly cars to reduce the environmental effects of vehicle use in cities and promote more sustainable cities (Grieco et al, 2012). Since the Kyoto protocol, the UK (and the majority of countries worldwide) has had policies in place to reduce the countries environmental footprint.

Traffic calming started in Holland in the 1970's, using "Woonerf" schemes, which introduced the concept of vehicles and pedestrians sharing road space. In Woonerf designs streets were reconstructed to reduce vehicle priority with speed humps, chicanes and other measures included to reinforce the residential setting, ensuring that drivers were aware that the residents had priority over their space. However, these measures proved to be expensive and overtime these measures were replaced by cheaper traffic calming measures (Harvey nd.:section 3.0).

So traffic calming can be defined as various design features and strategies intended to reduce vehicle traffic speeds and volumes on a particular roadway. Table 2.8 describes some of these strategies (www.vtpi.org). Traffic Calming projects can range from minor modifications of an individual street to comprehensive redesign of a road network. Home Zones refers to an area with extensive Traffic Calming. Traffic Calming is becoming increasingly accepted by transportation professionals and urban planners.

Table 2.8: Traffic calming strategies and devices (Source www.vtpi.org)

Type	Description
Curb extensions "pinch points"	Curb extensions, planters, or centreline traffic islands that narrow traffic lanes to control traffic and reduce pedestrian crossing distances. Also called "chokers."
Speed tables, raised crosswalks	Ramped surface above roadway, 7-10 cm high, 3-6 m long.
Mini-circles	Small traffic circles at intersections.
Median island	Raised island in the road centre (median) narrows lanes and provides pedestrian with a safe place to stop.
Channelization islands	A raised island that forces traffic in a particular direction, such as right-turn-only.
Tighter corner radii	The radius of street corners affects traffic turning speeds. A tighter radius forces drivers to reduce speed. It is particularly helpful for intersections with numerous pedestrians.
Speed humps	Curved 7-10 cm high, 3-4 m long hump.
Speed lumps	Two or more speed humps with gaps spaced to allow fire-rescue vehicles to pass without slowing.
Rumble Strips	Low bumps across road make noise when driven over.
Chicanes	Curb bulges or planters (usually 3) on alternating sides, forcing motorists to slow down.
Roundabouts	Medium to large circles at intersections.
Pavement treatments	Special pavement textures (cobbles, bricks, etc.) and markings to designate special areas.
Bike lanes	Marking bike lanes narrows traffic lanes.
"Road diets"	Reducing the number and width of traffic lanes, particularly on arterials.
Horizontal shifts	Lane centreline that curves or shifts.
2-lanes narrow to 1-lane	Curb bulge or centre island narrows 2-lane road down to 1-lane, forcing traffic for each direction to take turns.
Semi-diverters, partial closures	Restrict entry/exit to/from neighbourhood. Limit traffic flow at intersections.
Street closures	Closing off streets to through vehicle traffic at intersections or midblock
"Neotraditional" street design	Streets with narrower lanes, shorter blocks, T-intersections, and other design features to control traffic speed and volumes.
Perceptual Design Features	Patterns painted into road surfaces and other perceptual design features that encourage drivers to reduce their speeds.
Street Trees	Planting trees along a street to create a sense of enclosure and improve the pedestrian environment.
Woonerf	Streets with mixed vehicle and pedestrian traffic, where motorists are required to drive at very low speeds.
Speed Reductions	Traffic speed reduction programs. Increased enforcement of speeding violations.

2.4.2 History of traffic calming measures

During the 1950s and 1960s car ownership in Europe increased almost exponentially. This resulted in rapid increase in traffic and caused extreme pressure on the existing street network. At that time, transport professionals were interested in facility building to solve capacity problems and the solution was adding more lanes to the roads or by building new traffic roads leading into and through town centres. Many breakthroughs of streets were implemented in the belief that very optimistic traffic forecasts would prove true. Early traffic planning moved in the name of progress without any significant objections from residents and light road users. The increasing and unsolved capacity problems of roads caused queuing and delay, which motorists often considered unacceptable. As a consequence, many motorists bypassed the roads by using the adjacent local roads as shortcuts. In many local areas, the traffic became too intense for children to play and adults to stay on or near the local roads. In many places, they tried to solve the through traffic problem by closing the troubled local roads at one end or midway. However, the fire brigade and police authorities protested, seeing it as a hindrance to responding to emergency calls. Motorists claimed that the closings caused inconvenient detours. As a result, the question of where to close the road continued to be a point of disagreement in many places.

Gradually, as historical buildings of national interest were bulldozed and whole districts were split up by new traffic arteries, a protest movement grew up. In many places it managed to stop or delay road projects. In many main streets in the large town centres pedestrian streets were laid out as an experiment. Vans could bring goods to the shops only within defined hours. Many of these experiments were made permanent because they turned out to be very successful for shopkeepers as well as for customers. The rapidly increasing traffic intensity on both traffic roads and local roads led to an increase in accidents, particularly between cars and light road users.

At the beginning of this period there was a strong belief that traffic problems, particularly traffic safety problems, could be solved by separating the slow-moving light road users from the fast-moving heavy road users and by classification of road network in terms of function and capabilities. At the same time, oversight, simplicity, and uniformity were emphasised in the design of the traffic environment. The idea behind this work was to remove conflicts between cars and light road users. The two categories were to have their separate road networks, and crossings between paths and roads were to be grade-separated. These traffic planning ideas were internationally recognized and applied throughout Europe, where urban development's took place on virgin lands.

However, implementing the ideas in existing cities created problems. In Holland, narrow streets in the old towns had too little space left for the separation model. In Delft, residents lost patience with through traffic and alien parking in their local streets. Following the lead of the 1968 anti-authoritarian movement, they took the matter into their own hands. With the town planner Joost Vahl as their anchorman the narrow streets along the channels were reconstructed for “traffic integration.” The entire road area was designed and organised as a leisure area with tables, benches, sand boxes, but leaving space for cars to travel through the area at walking speed. Speed was physically reduced by means of humps and narrowing. This solution, known as the “Woonerf design” was the first traffic calming initiative. The Woonerf idea swept through the whole of Europe, especially from the mid-1970s. An early systematic approach to speed management emerged from the Swedish SCAFT guidelines (Statens Byggeforskningsinstitut 1969), which suggested a speed limit less than 50 km/h for the two lowest road classes (primary and secondary access roads). In 1973, Sweden allowed the marking of local streets with a speed limit of 30 km/h. In Denmark, an amendment to the Road Traffic Act in 1976 permitted the establishment of roads primarily for playing and pedestrians in which traffic took second place (Larsen et al. 1978). Give-way was reversed on these roads: motorists were to yield to pedestrians. The Dutch “Woonerf design” which was legalised in Holland in 1976, became known in Denmark as “Section 40 areas” or “shared areas.” As in Holland, speed was controlled primarily by physical speed reducing measures. The Danish Section 40 roads were to be established mostly where residential zones were particularly in need of areas for pedestrians and playing. In the local roads where regard for the light road users made it desirable to reduce the speed of the traffic to a maximum of 30 km/h without reversing the give-way obligation, physical speed reducing measures were allowed. Such roads came to be known as “silent roads.” In connection with the first oil crisis in 1973, several restrictions were temporarily introduced on car traffic with a view to saving energy throughout Europe. One measure was the “no driving on weekends” prohibition. Driving was allowed in vital cases only. This encroachment on freedom to move in combination with the resulting silence and clean air had a profound impact on people’s perception of the positive and negative aspects of traffic. It prompted a growing concern for the environment among residents in traffic issues.

One other means to control fuel consumption was by introducing speed limits. Before the oil crisis, speed limits were fairly liberal, and the reason for using them was more concerned with the safety of the motorists than with the light road users. The Traffic Acts of most countries did stipulate that one should drive as carefully as the conditions would allow. Nevertheless, it was interpreted by many motorists to mean the capabilities of driving dynamics rather than paying attention to the surroundings and the safety of other road users.

In the beginning, traffic calming on local roads was relatively expensive. In view of the short supply of money, particularly in the public sector, many people found that after the second oil crisis in 1979, the money was better spent on improvement in traffic roads where accidents were more frequent. At some sites, physical speed reducing measures were applied to traffic roads despite opposition from business circles, bus companies, motorists and, to some extent, the police. Experience from a large-scale Swedish experiment involving the marking of a speed limit alone without any physical speed reducing measure had indicated an effect on traffic safety, but no significant reduction in speed to the desired 30 km/h down from 50 km/h had been obtained. The same result was experienced in Norway where increasing traffic and a reduced respect for speed limit signs aggravated traffic safety and security problems for residents near village through roads. The construction of a bypass was very costly in the Norwegian mountains, which forced the Norwegians to think along new lines. The Norwegians established three strategies for a solution to the problems. (Jensen and Kildebogaard 1981; Statens Vegvesen 1979).

The DfT has supported these kinds of schemes all over the UK, and it has been claimed that these measures improve accidents and safety especially in the very busy residential areas. As explained earlier, all measures are affected and regulations enacted to enforce its implementations (DfT: 2010b).

2.4.3 Traffic calming techniques

According to Transport for London (2005) there is a wide range of traffic calming techniques available, including visual appearance, speed cameras and variable signs, access control measures, priority changes, horizontal and vertical alignment changes.

A driver's behaviour can be changed by altering the road appearance encouraging drivers to slow down. This can be achieved by breaking up long lengths of wide road with visual measures such as road markings, to create the impression that the road is narrowing. A similar reaction can be achieved by using different coloured or textured road surfacing or by using road furniture such as bollards, islands or tree planting to alter the character of the road. This approach is particularly suitable for new developments. Speed cameras and variable signs are a feasible alternative to speed humps, either using spot speed camera's or time distance series of cameras, in which the average speed along long lengths of road can be calculated. Vehicle Activated Signs (VAS) can also be used to warn drivers that they are driving too fast.

Access control measures such as width restrictions can reduce the volume of traffic using a road for rat running. Changing traffic light phasing can also discourage traffic rat running along pedestrian or unsuitable roads. Mini roundabouts at road junctions can be used to slow traffic on all approaches to the junction. Chicanes can be used to deflect traffic making drivers slow to negotiate the road layout (TfL 2005).

Hargreaves (1997) points out that vertical access control measures include speed tables, speed humps and speed cushions. These methods must be designed taking account the needs of all road users especially in areas where there is a bus route. Harvey (nd.:section 4) describes speed cushions as raised portions of carriageway with a flat top, which extend over a section of the carriageway width. This design allows cyclists and large vehicles for example buses to pass the traffic calming measures unhindered.

Speed cushions can be either a single cushion located in the centre of the carriageway or two cushions located side by side. An alternative arrangement is to have two cushions with build-outs to prevent cars parking close to the cushions, forming an obstruction.

Speed tables consist of an extended flat-top hump with a minimum 6 metre long plateau with ramps and are designed to reduce discomfort of traffic calming measures on long wheel based vehicles. Another traffic calming technique is to raise the levels of a junction on all approaches, which is similar to a speed table, but covers the whole junction, with the advantage of calming two streets with one measure. Rumble devices consist of installing coarse textured road surfacing located in strips at decreasing intervals, causing the driver to slow down. However, these need to be located away from residential areas as they can cause noise nuisance. Finally, round-top road humps can be used to create a barrier in the road making drivers slow to avoid vehicle damage (TfL 2005).

2.4.4 The benefits of traffic calming measures

Hargreaves (1997) summarised the benefits of traffic calming including that these traffic management methods could reduce the traffic using a residential road as drivers seek routes without traffic calming. Traffic calming measures can reduce the speed of vehicles and this has corresponding improvements in safety and a reduction in noise from high-speed vehicles. Another advantage is that the number of heavy goods vehicles using the residential street could be halved. The traffic calming measures could be designed and constructed to the same level as the footpaths thus creating a safe crossing area. The disadvantages of traffic calming measures include emergency vehicles could take longer to travel along a calmed road and the journey would not be as comfortable as driving along a road with no humps.

Int Panis et al. (2006) carried out a study on traffic calming measures in Belgium, where whole districts were converted in 30km/hr zones, usually in residential areas. The aim of these measures was to improve road safety. These schemes were also promoted as improving the environment through lower fuel usage and reduced air pollution. Int Panis et al. (2006) investigated the correlation between reducing traffic speed and air pollutant emissions. Using real life urban driving cycles and the VeTESS tool to calculate emissions for specific types of modern cars, Int Panis et al. (2006) compared real life emissions with artificially modified driving cycles limiting the top speed to 30 km/h where appropriate and elongating the cycle to preserve the original cycle distance. The study concluded that with the exception of PM from diesel engines, the most common air pollutants did not change substantially due to a decrease in speed.

Research shows that traffic calming measures can be effective in reducing speed, accidents and noise and that the most effective traffic calming measure with respect to speed reduction is vertical changes to the carriageway. However, these measures are only effective if the speed humps or speed table are spaced sufficiently close together to make drivers slow down. Harvey (nd.:section 5) points out that a survey of 35 traffic calming schemes in the UK found that the average reduction in speeds was 16 km.hr. If these measures are designed correctly, with measures located within 60m of each other, then it is possible to see that 85 percentile travel at a speed of less than 30kph. These reductions in speeds have a positive impact on accident rates, with slower vehicles reducing both the accident rate and the severity of the accidents. According to Pharoah & Russell (1989) a study in Germany found that accidents rates decreased from 6.2 per 100,000 of population to 2.3 per 100,000 in areas where traffic calming measures had been implemented. Harvey (nd.:section 5) also cites a study in Denmark which reviewed 600 traffic calming schemes in Denmark and found that these schemes had a 43% lower accident rate than untreated zones. Traffic calming measures can also lead to a reduction in noise, which is attributed to lower traffic volumes and speed. Pharoah & Russell (1989) suggest that traffic calming measures can also lead to a reduction in air pollutant emissions resulting from lower speeds but reduction levels were influenced by driving style. Harvey (nd.:section 5) cites a study in Germany which monitored vehicle emissions before and after the implementation of traffic calming and found that the traffic calming measures resulted in a decrease in Carbon Dioxide levels of 20% with a reduction of 10% in Hydrocarbons and 33% in Nitrogen Oxide.

In a Tyne and Wear study on bus lanes, which can be used as a means of traffic calming (Mulley et al, 2007), very few of the accidents in the study area were linked to the new priority measures on the traffic lanes. Contravention of the road traffic measures only occurred in 0.7% and 2.4% for different cases. However, a lower level of traffic was seen were it was postulated that it used different routes and cut through. There was uncertainty whether traffic journey times increased, with some increasing and some reducing although there were also other traffic changes at the time of the study which may have affected these results.

Car users are shown to dislike traffic calming measures in surveys, bus operators are shown to believe that any kind of priory system for buses was a good thing (Mulley et at, 2007), although cyclists and pedestrians are shown to generally have a more positive response to them. As they force traffic to move at a slower speed they are likely to reduce accidents and make the environment more pleasant for non-motorised transport and pedestrians. The lower speeds and potential requirement for vehicles to start and stop would result in higher traffic emissions, which would increase the influence of the cars on climate change, particularly from cold engines, when vehicles are on short journeys. The increased amount of stopping and starting could increase the noise level, although the overall lower speed would decrease the noise level so any assessment on noise levels would need to be considered more carefully on a case by case basis. As mentioned by Mulley et al (2007), as traffic calming measures could lead to traffic rerouting their journeys, it may just move the problem to another area rather than result in lower speeds and less accidents.

Hargreaves (1997) carried out a study into attitudes to traffic calming measures. The study involved asking residents of a residential area in Leeds to choose between three options, leaving the streets as existing without traffic calming measures, choosing round-topped road humps construction with tarmacadam or flat topped road humps constructed using block pavers. Respondents living on the primarily residential streets were asked to choose between three options. Respondents living in an area with mixed priority streets were given five options, the three previously mentioned plus an option for speed cushions, which are small tarmacadam humps that buses can straddle and small cars can avoid going over them. There respondents were also given an option of pinch points or chicane which is a localised narrowing of the roadway. All the devices were to be placed at 60m intervals and road humps were to be 100mm high. The study found that a significant number of residents on the mixed priority route were against traffic calming measures despite the higher volume of traffic and traffic speeds experienced along these roads. Residents in these areas justified their choice by stating that they had chosen to live in a mixed priority area specifically for easy road access and public transport routes, they had developed resilience to the impacts of high volumes of traffic and believed that these "through roads" were not suitable for traffic calming measures. On the mainly residential streets, the residents not in favour of traffic calming measures were strongly opposed to traffic calming schemes. The researchers concluded that people's views on traffic management measures such as traffic calming is largely based on current personal concerns and circumstances at that time. Where residents were in favour of traffic calming, road safety was a priority, stating that traffic calming measures would ensure that traffic was diverted to more appropriate roads. Aesthetics of the speed humps were important to residential areas. In the mixed priority areas, there was opposition to the pinch points as it was believed that these would cause problems for drivers navigating the road and could cause problems for parking. Some respondents believed that the flat topped speed humps could be a safety hazard as pedestrians may believe that they had priority over road vehicles. Most of those polled who were in favour of traffic calming chose speed cushions as the preferred method, stating that other types of traffic calming measures were uncomfortable for drivers (Hargreaves 1997). Speed cushions are also considered the best solution along bus routes as they have less impact on the bus, do not substantially affect bus passenger comfort levels and reduce speeds (TfL 2005).

2.4.5 Analysis of traffic calming measures

Relatively few studies have attempted to quantify the energy and environmental impact of traffic calming measures. Litman (1999) studied the benefit and cost of traffic calming measures and not surprisingly concluded that traffic calming strategies that reduce traffic speeds and smooth traffic flow can generally reduce air pollution, while those that increase the number of stops may increase emissions. He also found that when traffic calming reduces vehicle speeds from 50 km/h to 30 km/h for an ‘‘Easy Driver,” savings in CO, HC, Nox, and fuel consumption in the range of 13%, 22%, 48%, and 7%, respectively, are achievable. In the case of the ‘‘Aggressive Driver” savings in CO, HC, and Nox in the range of 17%, 10%, and 32%, respectively are observable with increases in vehicle fuel consumption in the range of 7%. He concluded that most emissions models are designed for highway conditions and are poorly calibrated for lower-speed travel and thus not effective in evaluating traffic calming measures.

Pharoah (1991), found that traffic calming measures with smooth and low speed driving in a high gear may result in relatively low emissions and that the effect of traffic calming strategies on air quality depends on how the scheme influences both the average speed of traffic and the amount of speed variation. While some studies found that traffic calming measures benefit air quality, several concluded they increase vehicle fuel consumption and emissions. Several previous studies indicated that traffic calming measures can increase the emissions from passenger cars. In particular, Hyden showed that traffic circles (or roundabouts) increased CO and Nox emissions by 5% (Hyden et al., 1995). Höglund and Niittymaki (1999) studied the effect of speed humps during peak and non-peak hours using the speed profiles of traffic simulation and computerized emission calculations and found that speed humps are responsible for an extra 76%, 32%, 26%, and 19% in HC, CO, Nox, and fuel consumption estimates, respectively, compared to a no-speed hump alternative for a 50 km/h speed limit scenario (Höglund and Niittymäki, 1999). Boulter (1999) also found that traffic calming measures increase HC and CO emissions by 54% and 59% respectively and CO2 emissions by 26% (Boulter et al., 1999). Boulter (1999) and his colleagues also developed a methodology for constructing the driving cycles of speed hump measures. The study utilized the measurement of the speed profiles of a large number of vehicles using a roadside Light Detection and Ranging (LIDAR) system (Boulter et al., 1999). Also, Daham et al. (2005) carried out research by simulating braking and acceleration events to mimic speed humps by driving a normal road using an on-road emission measurement device, found that speed humps increase HC, CO, Nox, and CO2 emissions by 148%, 117%, 195%, and 90%.

Ahn and Rakha (2009) carried out a case study to evaluate the energy and environmental impacts of various traffic calming measures. Second-by second GPS field data were collected using a passenger car and a sport utility vehicle at three different sites with different traffic calming measures, including traffic circles, speed humps, speed lumps, speed bumps, and stop sign intersection control measures. While traffic calming measures reduce vehicle speeds on neighbourhood streets and may contribute to enhanced road safety, these measures can result in significantly higher fuel consumption and emission rates when drivers accelerate aggressively. They also found that newly installed speed lumps could be responsible for extra fuel consumption. Traffic circles produced the least increases in vehicle fuel consumption and emissions and the case study showed that, in general, traffic circles allow smoother driving patterns with milder acceleration behaviour when compared to speed humps and stop signs. The results also demonstrate reductions when stop signs are replaced by traffic circles. The study indicates that by eliminating sharp acceleration manoeuvres significant energy and emission savings can be achieved. Consequently, significant improvements in air quality and energy consumption may be achievable through driver education.

Galante et al. (2010) investigated drivers' speed behaviour in a section of a rural highway crossing a small urban community in the existing scenario without any traffic calming device and in two different scenarios with traffic calming in the urban community. Two gateways and four integrative traffic calming devices along the route within the urban area were tested. The gateways were aimed at slowing down the vehicles entering in the built-up area, while the traffic calming devices were aimed at complementing the gateway effect inside the built-up area. Simulation results were validated by the comparison of speed behaviour in the real world and in the driving simulator, in the scenario without traffic calming. Analysis of simulation results showed a different behaviour of drivers approaching the urban community in the existing scenario and in the design scenarios. In the south direction, mean speed reduction ranging between 16 and 17 km/h, with 5% level of significance was observed. In the north direction, mean speed reduction equal to 11 km/h, with 10% level of significance, was observed. Differences between the two design alternatives were not significant. Along the urban community, a statistically significant mean speed reduction was observed only in the south direction. In the north direction, mean speed reduction was not statistically significant. Overall, combined results of cluster analysis and statistical tests showed that the treatments were more effective in the direction with higher speeds in the base scenario.

Elvik (2001) conducted a meta-analysis of 33 studies that have evaluated the safety effects of area wide traffic calming measures in urban residential areas. Traffic calming consisted of measures designed to discourage non-local traffic from using residential streets and reducing the speed of the remaining traffic. Roads designated as main roads were upgraded to handle a greater traffic volume without a corresponding increase in the number of accidents. On the average, evaluation studies showed that area wide traffic calming reduces the number of accidents by about 15% in the whole area affected by the measures (main roads and local roads combined). There was a greater reduction in the number of accidents on local roads (about 25%) than on main roads (about 10%). Results vary considerably between evaluation studies but the method adopted in the meta-analysis (random effects model) accounted for these discrepancies. Studies were classified in five groups, depending on how well the study design controls for confounding factors. There was a tendency, albeit not very strong, for weakly controlled studies to find greater effects of traffic calming than well-controlled studies. The results of the evaluation studies were stable over time and of similar magnitude in eight countries that have reported evaluation studies. It was in principle impossible to rule out the possibility that uncontrolled confounding factors account for the results of the evaluation studies. It seemed more likely that the results of at least the best-controlled studies mostly reflect the effects of traffic calming.

Boulter et al. (1999) developed a methodology for deriving cycles to represent driving patterns before and after the installation of different traffic calming measures. For the first scheme in the study the driving cycles were derived from a combination of remote speed measurements, obtained using a LIDAR device, and speed and gear-change data recorded using instrumented cars. The feasibility of selecting a number of instrumented car speed profiles to correspond to a representative sample of LIDAR profiles was confirmed in tests at TRL and in real traffic. It was found that the range of instrumented car measurements covered the range of the LIDAR measurements if the results from two different instrumented cars were used. However, although the LIDAR system was capable in principle of measuring ‘real’ driver behaviour, certain aspects of its operation suggested that it was probably not the definitive technique. A single driving cycle was considered sufficient to represent all categories of car. However, the amalgamation of mini-cycles resulted in driving cycles that were difficult to follow on the dynamometer and had unrealistic gear change patterns. Consequently, a smoothing function was applied to the speed data to make the cycle more driveable, and gear-changes were simply set to occur at given speeds. As gear-change data was no longer required for the remaining schemes, the LIDAR speed profiles alone would be used to construct the driving cycles for the remaining schemes. Cars which conform to a range of size and emission-control legislation were driven over the cycles on a chassis dynamometer whilst emissions of CO2, CO, HC, No*x*, and particulate matter were measured continuously. Emissions from heavy-duty vehicles will be estimated using speed-dependent functions. The emissions from each category of vehicle g/km were weighted in proportion to the total number of vehicles in that category observed passing through the scheme.

2.5 Transport problems in developing countries

In the developing countries, situation of transport related problems are not different form the developed world. Many cities of the developing countries are struggling with the congestion problems and pollution. With the advent of less expensive modes (i.e. motorcycles), the situation has worsened in many metropolis including Bangkok, Delhi, Karachi etc. In the large cities of the developing world, travel times are generally high and increasing, and destinations accessible within limited time are decreasing. The average one-way commute in Rio de Janeiro is 107 min, in Bogota it is 90 min. The average vehicle speed in Manila is 7 miles per hour. The average car in Bangkok is stationary in traffic for the equivalent of 44 days a year (Gakenheimer, 1999). The number of cars is increasing on the basis of increased populations, increased wealth, and increased commercial activities. Accordingly, in much of the developing world the number of motor vehicles is increasing at more than 10% a year–the number of vehicles doubling in 7 years. Although there is much less research and development in the field of planning technique in the developing countries and public budgets are limited, they have certain important advantages in mobility innovation relative to developed economies. These include some cases in which there is

1. Stronger authority to increase mobility. There are countries in which urban governments have much more authority than in the developed world. Many of the countries have more power in central government guidance of local action.

2. Lower personnel cost relative to capital costs. This simply results in different choices of actions, sometimes with consequences worth the attention of wealthier countries.

3. Fewer regulatory and legal barriers. These permit the introduction of guidance that would be halted in the developed world by fear of law suits in the case of malfunction.

4. Less convention in problem solving. In countries where transportation planning is a professional tradition, thinking is more conventional and there may be less scope for innovation.

5. A larger stake in solving mobility problems that better supports public action. This is because the problems are worse. The cities of the developing world have motorized faster, leaving urban structure further out of adjustment than in developed world cities.

6. Perceptibly growing problems. In many developing cities congestion is growing at a rate easily perceived year to year by even a casual observer. This public awareness is leverage toward action in some cities.

Transportation in UAE acquires a great deal of the public services investments. The overall federal and local investment spending on land transport projects in the UAE has touched Dh. 86 billion over the period from 1985 to 2002. According to a study by the Ministry of Planning, most of that amount was expended in construction, replacement, refurbishment, expansion, lighting and landscaping of roads, bridges and tunnels. The study indicates that the lengths of paved highways rose to 3969 kilometres in 2002 that is 393 kilometres more than the 1985 figure (www.uae.gov.ae/mop). The transportation system in UAE experiences many difficulties that may be summarized as bellow:

A study held by the Ministry of Planning, declares that the number of vehicles in the UAE almost doubled to reach 820,000 motors in 2002 from 443,000 in 1985, with an annual increase of 9.2 %, which is remarkably more than the population growth rate of 6.5 % and even higher by 7.1% than the annual national income growth rate. It attributes the increase in number of vehicles in the country to a group of factors, mainly the high living standards and competitive credit facilities on offer by financing agencies as well as other factors. The Abu Dhabi Emirate has the lion's share of vehicles, with 312,833 automobiles passing through its streets; these represent 42% of the total number of motors throughout the country, according to the study, Dubai comes second with 285,951 vehicles (38.4%) followed by Sharjah (9.8%), Ras Al-Khaimah (3.4%), Ajman (3.1%), Fujairah (2.4%) and Umm Al-Qaiwain (0.9%) (www.uae.gov.ae/mop).

Nowadays, Dubai is a materialized example for traffic congestion in UAE, due to increasing numbers of cars. Recent statistics assert that there are 465,000 vehicles registered in the Emirate, in addition to 5,000 taxi cars (www.dm.gov.ae). However, there is a significant amount of residents of neighbouring Emirates who are working in the city. This means there are more than a million vehicles on Dubai's roads, making an average of 3.1 million trips each day. Furthermore, the number of vehicles in use is increasing rapidly. The annual growth rate of vehicles in Dubai is currently 12% and the growth pattern is likely to continue. It is expected that Dubai's population will reach four million in 2020, while the number of trips is expected to go up to a staggering 13.1 million trips per day (Nick, 2005). Likewise, increasing numbers of vehicles affects strongly the other difficulties that the transportation system is undergoing in UAE. There is a common concern over rising pollution levels in UAE. Vehicles are to blame for 80% of pollution. Vehicular violations in the UAE caused environmental pollution through gas emissions beyond the limits allowed by the law set by the country, has ranged between 13 to 25 % during 1999-2003. Problems of environmental pollution resulting from car exhausts, has surfaced as one of the most acute problems of vehicles plying on the road (Mussallam, 2005). Emissions of harmful gases pose health and environmental hazards and need to be reduced to a degree that guarantees unpolluted air and a hygienic environment. This situation demands a thorough consideration of new public transport policies and for that proper assessment of these measures.

2.6 UAE background and transport system

The United Arab Emirates (UAE) was formed by the joining of some organized Arabian Peninsula sheikhdoms. Before it gained independence UAE was under the protection of Britain and was known as the Trucial Oman or in other words Trucial States. At around 1952, the Trucial Council which comprised of rulers from the different sheikhdoms was formed with the main aim of ensuring the sheikdoms adapted common policies and especially in administrative matters. In 1971 the sheikhdoms acquired independence from the British and changed the name to UAE under a common constitution. At the time that the UAE was being formed i.e. 1971 only six of the seven sheikhdoms were on board with the last sheikhdom joining the UAE in 1972 (Walker and Butler, 2010).

The most common means of transport in the UAE is usually by cars. Surveys have shown that cars constitute the largest means of transportation in UAE while buses and motorcycles then follow respectively. For a person to own car in UAE he or she must have a UAE residence visa otherwise taxis are the most common means of transport. The transport system in UAE is a bit strange as taxis are only allowed to take a passenger from their registered Emirate and drop them anywhere but cannot pick passengers from any other Emirate apart from where they are registered (Oxford Business Group, 2008). This system in one way or another might prove to be costly to the passengers because when a taxi drops a passenger in another Emirate it has to return empty without any passengers and since it’s a business the total cost is passed onto the passenger. As a way of reducing the cost, many people prefer boarding the same taxi. Most of the taxis charge their customers by meter while others base their charges on the prices issued by the Emirates. Buses are also commonly used but are not preferred by many passengers because of the rigid routes that they have to follow (Nick, 2005).

2.6.1 Transport and traffic problems in UAE

According to El Mallakh (1981), transportation is a major component of any society across the globe but with most of the transportation systems in UAE relying on fossil fuels which have been termed as major cause of environmental issues such as global warming there have been calls for technology that can solve the transport system while at the same time safeguarding the environment. Evidently, with most of the cities in UAE experiencing transformations in several aspects such as economic and social, physical transport infrastructure have been affected in one way or another. Most of the transformations that have taken place in most cities of UAE have been initiated by other things other than sustainable development. The transport systems in UAE have consumed a lot of resources with most of those resources being channelled to construction of transport infrastructure (Hester and Harrison, 2004).

El Mallakh (1981) points out that the transportation in UAE and specifically the road system experiences several problems with the major ones being an ever increasing number of vehicles. A survey carried out in UAE showed that the number of vehicles almost doubled between 1985 and 2002. The amazing bit of the survey was that the number grew at a higher rate than any other sector including the population and the national income. With regard to this, the main reasons as to why the rate at which vehicles increased was high include high standards of living among the residents of UAE, and financial agencies that are offering credits at very competitive rates among others. Among all the seven Emirates, Abu Dhabi has been found to have the greatest share of all the vehicles in UAE with an approximation of 42%. The statistics also showed that Dubai has the second largest number of cars in UAE. Residents from neighbouring Emirates who work in Dubai seem to increase the number of cars found in the city. It is estimated that the rate at which cars in Dubai are increasing is about 12% but with likely to continue increasing with the increase in population, which something will further increase other types of problems associated with traffic in UAE (Al-Zubaidi and Sabie, 2002).

Another challenge that UAE transport system faces is the increasing number of road accidents. The issue of road accident is not only in UAE but a global challenge with statistics from World Health Organization (WHO) showing that more than 15 million people lose their lives as a result of road accidents. The statistics further show that road accidents are more rampant in developing countries than in developed countries. Road accidents have been described as the second largest cause of death among the UAE residents. Further still road accidents cause more trauma than any other form of accidents (Al-Zubaidi and Sabie, 2002). It has also been found that most of the UAE citizens lost a lot of property through road accidents. It is worthy noting that the accidents have far reaching implications on the socio-economic activities of UAE since a lot of resources have to be spent in addressing issues related to road accidents. It is approximated that UAE experiences fatal road accidents six times more than United States or even Europe. For example, in the year 2002, UAE recorded about 10,800 road accidents with more than 750 people losing their lives in those accidents (El Mallakh, 1981).

Another problem brought about by traffic not only in UAE but across the globe is pollution of the environment. As earlier mentioned, the number of vehicles in UAE has been growing at an alarming rate and since they make use of fossil fuels their contribution to pollution has been rated as the highest with about 80% of all the pollution in that country being directed to transport mechanisms (Al-Zubaidi and Sabie, 2002). In an effort to reduce the amount of greenhouse gases emitted by vehicles, UAE came up with some laws which have not been fully adhered to. Greenhouse gases which mostly originate from fossil fuels and in particular vehicles result to global warming (Hensher and Button, 2003). Vehicle emissions are not only harmful to the environment through causing of global warming and climate change but also on public health as a number of those emissions have been found to be carcinogenic in nature. This is a great concern especially given that a very large portion of UAE residents live in cities which are in turn overcrowded with vehicles whose emissions pose a great risk to their lives. Traffic police in UAE have been involved in monitoring the motorists who do not adhere to laws that are intended to reduce traffic pollution. Apart from the emission the traffic also pollutes the environment through noise pollution and therefore measures should be taken to ensure that the ever growing vehicle number is constrained and the issue of transport demand handled in a sustainable manner. For this to be so there will be need for policies and supportive framework which will ensure such measures are taken and implemented fully (Nick, 2005).

2.6.2 The travel demand management in Abu Dhabi city and Dubai city

According to Schulte-Peevers (2010), Abu Dhabi is the largest city in the Abu Dhabi Emirate and it is also used as the centre of the government. The city has a population of about 1.5 million people and plays host to headquarters of quite a number of oil companies. With that kind of a population, government offices and a number of oil companies headquarters, it is essential for Abu Dhabi to manage its transportation effectively otherwise businesses in the city might be greatly affected. In Dubai the transportation is usually managed and controlled by the Dubai's Roads and Transport Authority (RTA) (Littman, 1999). As mentioned earlier most of the transportation in UAE depends on road transport and mostly cars and buses. The RTA runs a bus system which operates in 193 routes during weekdays and transports more than 30 million people every week. Despite having a very large public transport bus system, the demand is far higher than the system can hold and therefore in busy stations commuters can spend well over an hour before boarding a bus.

Even though it was earlier mentioned that the number of vehicles in UAE increases at a faster rate than the population, the scenario is different when it is compared between the public buses and the number of commuters i.e. the number of commuters increases at a faster rate than the number of public buses hence the reason why commuters may stay well over an hour before getting a bus to board. In an effort to address the challenge the RTA has always endeavoured to increase the number of buses operating in the different routes (Litman, 1999, : Nick, 2005). A very good example is where the RTA decided to have a new fleet of buses that have state of the art technology such as GPS and voice systems that are used to announce next station among others.

It is believed that Dubai is the most congested in terms of commuters in the whole of Middle East something which makes residents spend about two hours commuting to and from work. In response to the traffic congestion the UAE government has invested greatly in the traffic infrastructure. Most of the Dubai's residents worry more about traffic congestion than anything else. Dubai has the largest number of registered car ownership with about 540 people out of every 1, 000 owning a car a rate which is far higher than those of other major cities in the world such New York, London and Singapore among others. Some analysts argue that the traffic congestion that is experienced in Dubai and UAE in whole is due to flawed road system (Al-Zubaidi and Sabie, 2002).

In an effort to ease traffic congestion mostly in Dubai, RTA decided to come up with a master plan which involves the construction or extension of the roads by a further 500km with about 120 interchanges by the year 2020. The master plan is also aiming at reducing the number of deaths that result from traffic accidents from 17% to about 5% before 2020 (Sambidge, para 2). RTA is also considering coming up with policies that will reduce the rate of vehicle ownership while at the same time make it more attractive for the residents to make use of public transport. The specific measures which the master plan proposes include bus-dedicated lanes, separate zones for both pedestrians and cyclists, the use of toll gates systems and coming up with policies and laws that will govern how vehicles are registered and drivers licensed (El Mallakh, 1981). This move will ensure that the most competent driver gets to be licensed and faulty vehicles which have higher chances of causing accidents do not find their way to the UAE roads. As earlier mentioned the RTA proposes to introduce a new fleet of public buses with state of the art technology which would be used to encourage people to make use of public transport rather than have many cars that will result to traffic congestion.

2.6.3 Speed calming measures in Abu Dhabi city and Dubai city

One method that authorities in UAE and specifically in Dubai and Abu Dhabi have realized could be of great use in curbing speeding is the use of painted pavements, sleeper lines and new signs. The authorities have also identified the strategic points where these measures will be put i.e. transitional distances where it is alleged that motorists either accelerate or decelerate (Ismail, n.d para 1). This implies that the plan intends to have these speed curbing measures installed in all major roads and specifically transition points of rural and urban. Painting the road with colour red would be used to mean that there is a drop in speed limit and therefore the driver should adhere to the warning by dropping the speed to the required limit. The colour if effectively used would always act as an alert for drivers that they are entering an area with a different speed limit and therefore their attention is fully required.

The installation of sleeper lines which is another proposed measure is to ensure that inattentive drivers are always reminded of the potential hazards that are on the road. The sleeper lines are also referred to as rumble strips and they work by sending some vibrations right from the wheels through the car body to the driver and also by making some rumbling sound that is audible enough to attract the attention of the inattentive driver. The rumbling devices mostly alert drivers when they seem to drift away from their lanes and has been termed to be very effective in reducing the accidents that are caused by inattentive drivers (Ismail, n.d para 4).

The rumbling devices apart from warning drivers when they drift also warn the drivers when there is a situation that warrants them either to stop or to detour. Another measure that was taken involved the changing of numerals that are used to indicate speed from Arabic to English in order to avoid confusion. Initially the signs that were in use incorporated numerals from both the Arabic and English languages with some text which clearly indicated the sort of vehicle but the current measure involves only the English language and in place of the text there are icons which show the type of vehicles affected by the speed limits. There has been a reduction of the distance interval between the sign posts from the previous 10km to 5km. The aim of reducing the interval by half is to increase the frequency at which the drivers are reminded of the speed limits they are required to be driving at (Ismail, n.d, para 3).

2.6.4 Assessment of travel demand management and speed calming measures in UAE

There are several methods that are used to asses travel demand management (especially bus lane scheme) and speed calming measures in Dubai and Abu Dhabi cities. The RTA has been mandated to carry out the assessment and management of transport means and therefore all measures taken up to reduce traffic congestion pass through it (Bener, A., Breger, A. and Al-Falasi, A, 1994). The only major method that can be used to assess travel demand management and speed calming measures is by conducting regular surveys and then analysing the data. The survey could be used to determine the number of people in the different categories such as those using public transport systems, those using private means and those who own cars but prefer using public transport. This data would be useful in assessing travel demand management only even though it could in one way or another impact on the speed calming measures.

Assessment of speed calming measures would be carried best by determining the number of accidents that have been caused by over speeding and in areas where the speed calming measures have already been installed. With the data it is then easy for the RTA and the UAE authority in general to determine whether the speed calming measures have been effective or not.

2.6.5 Efficiency of the transport systems in UAE

The transport system and especially the bus lane scheme and speed calming measures are not as effective as they should be. This is because if they had been effective the issue of traffic congestion would have been solved and road accidents caused mostly by over speeding greatly reduced, but this is not the case as traffic congestion is still a problem in Abu Dhabi and Dubai (Bener, A., Breger, A. and Al-Falasi, A., 1994). The aim of the bus lane scheme was to ensure that buses have their own exclusive lanes with the roads in order to ensure that they reach their destinations on time and that the public do not have to wait for buses. Despite this there has been over congestion with so many people waiting for about an hour before boarding a bus something which makes many commuters revert to other means of transport such as using private cars which then enhances the problem of traffic congestion (Al-Zubaidi and Sabie, 2002).

Even though the bus lane scheme might have been useful in ensuring that buses reach their destination without delay, it has not been effective in dealing with the whole situation of traffic congestion. The issue of speed curbing measures have been to some extent useful in reducing the number of accidents that have been caused as a result of over speeding. It is worth noting that the measures and especially those touching on curbing speed cannot be termed to be effective or ineffective as they depend on the other factors such as the willingness of the drivers to obey the rules.

Since the issue of traffic congestion in UAE and especially in Dubai and Abu Dhabi seems to be recurrent there is need to have short, medium and long term solutions. The short term measures especially as it regards to bus lanes would be to increase the number of buses and to have them in different parts so that passengers do not have to wait for long before boarding a bus (Nick, 2005). Another measure would be to increase the number of lanes set for both taxis and busses and if possible have each category have their own lanes as a way of improving efficiency within the transport system. In the future the RTA should consider prohibiting private cars from entering certain sections of the city i.e. through legislation the RTA should ensure only buses and taxis enter certain sections of the city (Rodrigue, J., Comtois, C. and Slcak B, 2009). This would greatly reduce traffic congestion while at the same time enhancing efficiency within the transport systems.

The RTA should consider other public transport means such as railways which are very fast and transport a lot of people simultaneously, this system that is widely used in some of the developed countries of the west and have proven to be cheap, fast and more reliable especially where people are travelling over long distances such as between Emirates (Rodrigue, J., Comtois, C. and Slcak B, 2009). The RTA would then ensure buses pick up the passengers from the rail stations and drop them in several bus stations in the cities from where they can walk to their points of interests or take taxis. In terms of speed reduction, the RTA should ensure that the drivers who are licensed are competent enough and that they fully understand the different road signs as well as the repercussions of breaking them. It is also advisable for the authorities to ensure that they there are enough police officers and monitoring devices to monitor and arrest those who break the laws (Musallam, 2005).

2.7 Gaps in the literature

This literature review has shown that vehicle emissions are damaging the environment, with potentially catastrophic global consequences. There is evidence that people are aware of the implications of car travel especially when these include delays to personal journeys, congestion and obvious air pollution. There is also evidence that people are reluctant to change travel patterns. Government policy is determined to reduce the adverse impacts of car travel and to promote more sustainable living. Transportation planners can provide data on current vehicle emissions and predict future emissions using driving cycle analysis. There are a number of driving cycles available, with the most commonly used being the American and European versions, However there is increased awareness of the need for city specific driving cycles since emissions depend on a wide number of variants. The variants that affect the level of vehicular emissions include speed, type and model of vehicles, the age and maintenance of that vehicle, temperature and manner of driving. There are a number of measures that can be implemented using travel demand management, which have been proven to reduce the negative impacts of car travel. These measures include major schemes such as giving buses greater priority on road space or congestion charging. Measures could be much simpler for example implementing area wide traffic calming. These measures can encourage drivers to drive slower and can also be used to encourage a modal shift towards greater use of public transport. The literature review demonstrates that these measures are most affective if whole areas are considered, as demonstrated by the London Bus Initiative. Driving cycles could be used to inform and predict the potential effects of travel demand management policies.

The literature review presented above suggests that transportation problems in terms of congestion and environmental degradation are abundant both in developed and developing countries. Many TDM (Travel Demand Management) measures have been tried by the policy makers and are continuing to test different techniques to facilitate mobility and decrease the environmental impacts of transport. The literature suggests that driving cycles have potential to test and assess different TDM measures in terms of their applicability and use.

The studies carried out so far generally deal with only use of driving cycles as a tool to measure environmental emissions and its use as a rather powerful and common technique to assess the evaluation of different TDM techniques is ignored. There have been attempts to study TDM measures in terms of traffic calming and speed measurements with driving cycles. However, there are certain gaps in the study of different TDM measures considered in the assessment not just partial studies on the estimation of speed and emissions.

It is surprising to see that literature has few studies that comprehensively link the driving cycle with TDM techniques and their assessment. There are numerous TDM measures now at hand and are implemented merely considering operational and travel time savings. It is important to study the influence of these TDM techniques in terms of many other less tangible criteria like speed, emissions, idling time, etc.

CHAPTER 3

CASE STUDIES

3. 1 Introduction

In this chapter a description of the selected case studies for this research are presented. Three case studies are investigated; two case studies in Edinburgh (UK) and one case study in Abu Dhabi (UAE). In Edinburgh the three case studies are: bus traffic corridors and traffic calming corridors and bus only corridor. In Abu Dhabi, two traffic corridors have been studied.

Firstly, three bus traffic corridors in Edinburgh were investigated to assess the performance of traffic. In this case, the performances of both the buses and the private cars along the bus lane corridors have been investigated. The aim here is to assess the impacts of bus lanes on the operation and performance of both cars and buses. These three corridors are referred to in this study as “Edinburgh bus traffic corridors”.

Secondly, there are four “Edinburgh traffic calming corridors”; three with traffic calming measures and one used as a control corridor. The performance of the cars on these corridors has been investigated. It should be added here that the choice of TDM measures for case studies was influenced by the Edinburgh context, i.e. there are many other TDM measures that could have been considered if suitable case studies were available.

Finally, there are two traffic corridors in the city of Abu Dhabi, and these are referred to as “Abu Dhabi traffic corridors”. On these corridors, the performance of the cars and buses are investigated and compared to that of cars and buses in Edinburgh.

3.2 Why these case studies?

The city of Edinburgh is selected because it has a very good public transport system which is often claimed to be efficient, effective and reliable. The statistics revealed a 27 per cent increase in the volume of passengers since 1998 (Edinburgh Evening News, 2005). According to the UK Department for Transport (DfT) publication on Bus Priority (2010b); Greenways Bus Lane Strategy in Edinburgh was implemented in 1999 costing approximately £500,000/km. The scheme studied A8 corridor 6.7 km long and A900 corridor 2.2 km long. It has been claimed that bus lanes improve the performance of traffic and save journey times for cars and buses as well as increase the bus patronage; it is also claimed that as a result, these schemes should have positive impacts on the environment. One aim of this research is to carry out a more thorough investigation of the impacts of bus lanes on traffic performance and to provide evidence on the possible impacts of bus lane corridors on the environment.

In addition, Edinburgh has a unique corridor which is completely devoted to buses (Princes Street). This corridor represents an interesting opportunity to examine as a case study in this research. It should be added here that this particular corridor is going to change very soon after the operation of the tram lines in Edinburgh, and that makes this corridor of special interest and value to consider as a case study in this research. Therefore, it was decided to use the driving cycle analysis and techniques to investigate impacts of bus lanes on traffic performance and on environmental issues.

The second transport policy which is increasingly implemented in the city of Edinburgh is traffic calming policies. These policies are implemented in order to calm traffic specifically in residential area, to reduce accidents and to improve safety issues. While there is evidence that these measures and polices have positive impacts on accidents reduction and safety improvements, there is not much investigations on the possible impacts on other environmental issues such as impacts on emissions. Reducing speed by implementing speed calming measures requires the vehicles to slow down (i.e. decelerate) then accelerate again. Previous work suggests that increase in acceleration and decelerations would results in increase in emissions. These emissions especially at the residential areas where there are more elderly and young children, who would be more negatively affected by these emissions might outweigh the advantage or the gains it achieves from reducing speeds. Therefore, utilising the principles of driving cycle analysis to assess the impacts of these policies seems both very interesting and very relevant from policy and from the society point of view. As discussed earlier, it should be added here that the choice of TDM measures for case studies was influenced by the Edinburgh context. It is possible therefore to consider other TDM measures in further studies as appropriate.

The final case study in this research is the traffic corridors in Abu Dhabi. Abu Dhabi city is a unique example of a city in a developing country. It is the capital and the second largest city of the United Arab Emirates in terms of population and the largest of the seven member emirates of the United Arab Emirates. The public transport system in the city however has only been available on the island of Abu Dhabi since June 2008. An initiative by the Abu Dhabi Department of Transport made available the first four bus routes and new and refurbished buses. The buses were free until February 2009. The traffic therefore is car dominated and there have been efforts to provide more public transport facilities and making them attractive. Hence the study of driving cycles is needed to understand the traffic characteristics and applicability of more public transport friendly policies.

3.3 Overview of the case studies:

The three case studies are detailed in this section. More discussions and details are presented in Section 3.4 below.

Firstly, the Edinburgh bus traffic corridors consist of:

1. A corridor with a bus lane (i.e. a lane is used exclusively by buses from (7.30-9.30 am and from 16.00-18.30 pm). This type of corridor is referred to in this study as a "bus-lane corridor". These corridors are represented in this study by corridor A7 (Nicolson Street) in Edinburgh.

2. A corridor with mixed traffic. That is the bus as well as all other traffic share all the lanes of the corridor. These types of corridors are referred to in this study as "mixed traffic corridors". These corridors are represented in this study by corridor A702 (Morningside Road) in Edinburgh.

3. A corridor which is designated to buses, which is in fact a very special case. However, Princes Street in Edinburgh is designated to bus and taxi operations only and no other traffic can use the road. Therefore, this has been an interesting case which was worthy of investigation and comparisons with other traffic corridors. These types of corridors are referred to in this study as "bus-only corridors", and represented in this study by Princes Street corridor in Edinburgh.

In total, there were twelve sets of measurements, seven measurements for buses (three on A7, two on A702 and two on Princes Street) and five measurements for the private car (three on A7 and tow on A702).

Secondly, the traffic calming corridors consists of:

1. A corridor with a 20 mph zone speed cushions, speed humps and cobbled street surface. This type of corridor is referred to in this study as a "Traffic calming-corridor-1". These corridors are represented in this study by corridor 1 (Iona Street) in Edinburgh.
2. A corridor with a 20 mph zone with speed humps. This type of corridor is referred to in this study as a "Traffic calming-corridor-2". These corridors are represented in this study by corridor 2 (West Bryson Road) in Edinburgh.
3. A corridor with a 20 mph zone with speed humps and raised junctions. This type of corridor is referred to in this study as a "Traffic calming-corridor-3". These corridors are represented in this study by corridor 3 (Montgomery Street) in Edinburgh.
4. A corridor with no traffic calming measures. This type of corridor is referred to in this study as a "control corridor". These corridors are represented in this study by corridor 4 (Polwarth Terrace) in Edinburgh.

In total, there were four sets of measurements, one set of measurements for cars in Iona Street, one set of measurements for cars on West Bryson Road, one set of measurements for cars on Montgomery Street, and one set of measurements for cars on Polwarth Terrace

Thirdly, the traffic corridors in Abu Dhabi consist of:

Two corridors with mixed traffic (i.e. all traffic shares all lanes on the corridor). These corridors are represented in this study by Airport Road and Elektra Road in Abu Dhabi. In total, there were eight sets of measurements, four measurements for buses (tow on Airport Road and tow on Electra Street) and four measurements for private cars (tow on Airport Road and tow on Electra Street).

3.4 Specific characteristics of the selected case studies

3.4.1 Traffic corridors for bus lane investigation in Edinburgh

As mentioned above, in order to investigate impacts of bus lanes on traffic performance, driving cycle was investigated on three traffic corridors in Edinburgh; a corridor with a bus lane, a corridor with mixed traffic (no bus lane) and a corridor which is dedicated for buses and taxis only. Ideally, it is required to identify two similar corridors in terms of traffic volumes; one with bus lane and one without. However, it seems that in Edinburgh most of the busy traffic corridors already have bus lanes in operation. Therefore, it was attempted to select two corridors which are similar in terms of the traffic flow characteristics as well as the general geometrical characteristics.

3.4.1.1 A7 Corridor (from North Bridge/ Market Street‘s traffic signal to South Clerk St/ W Perston St‘s traffic signal):

The A7 begins its course in central Edinburgh, at the A1/A7/A8/A900 junction at North Bridge as a non-trunk road before passing through the city's south-eastern suburbs. This part of the A7 was the former route of the A68 (the old A7 used to be what the A701/A772 at Gilmerton is now). The measurements of driving cycle for bus and car on the A7 started from North Bridge/ Market Street‘s traffic signal to South Clerk St/ W Perston St‘s traffic signal. The investigated A7 corridor is a single carriageway; it has two lanes, one lane for buses and other one for all other type of vehicles. The length of the investigated corridor is approximately 0.9 mile (Figure 3.1). Table 3.1 shows the characteristics of this corridor.

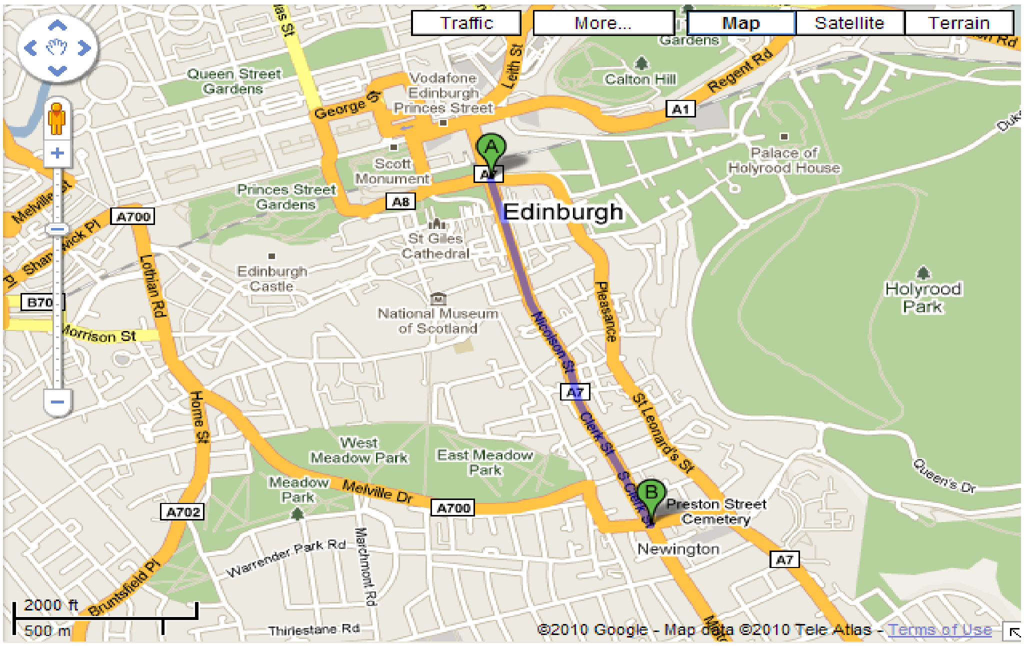


Figure 3.1: The A7 traffic corridor (Source: Google Maps)

Table 3.1: The characteristics of the A7 Corridor

The corridors	**Number of bus stops**		**Number of Signalised junctions**		**Number of pedestrians crossing**		**Bus frequency/hr**		**Number of bus routes**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
A7 (Bus lane)	7	8	6	6	6	6	57	57	10	10	Single carriageway	2	0.9 miles

The corridor is very busy during the peak hours, because the investigated part has six signalised junctions. The corridor has seven bus stops inbound and eight bus stops outbound. It has six pedestrian crossings in both directions. The buses frequency are 57 inbound and 57 outbound. This corridor has 10 bus routes for each direction. The following Table 3.2 shows the traffic volume on the investigated part of the A7 corridor (Source: Edinburgh City Council).

Table 3.2: Traffic flow on the A7 on three time periods (Source: Edinburgh City Council).

Time Period	Pedal Cycles	Motor Cycles	Cars & Taxis	Mini-Buses	Midi-Buses	Single Deckers	Double Deckers	LGV's	MGV's	HGV's	Total
8.00-9.00 (IN)	45	8	438	1	2	18	57	63	15	2	649
PCU 8.00-9.00 (IN)	18	3	438	1	2	45	143	63	15	5	732.7
8.00-9.00 (Out)	26	3	199	4	1	14	47	41	19	2	356
PCU 8.00-9.00 (Out)	10	1	199	4	1	35	118	41	19	5	433.1
9.00-9.15 (In)	48	0	348	0	4	16	52	56	12	4	540
PCU 9.00-9.15	19.2	0	348	0	4	40	130	56	12	10	619.2
9.00-9.15 (Out)	20	0	116	0	0	12	60	36	24	4	272
PCU 9.00-9.15	8	0	116	0	0	30	150	36	24	10	374

3.4.1.2 A702 (from Tesco Metro Junction to Comiston Road with Greenbank Crescent junction), (this corridor has no bus lane):

The A702 corridor starts as a primary route at the Tollcross junction in Edinburgh, and continues south until it meets the Edinburgh City Bypass (A720) on the city's outskirts. In the city is known as Home Street, Leven Street, Bruntsfield Place, Morningside Road, Comiston Road and finally Biggar Road. It continues in a south-westerly direction through the Pentland Hills to Biggar, before following the Clyde Valley. The route is a major commuter route for residents of Carlops, West Linton and Biggar who work in and around the Edinburgh area. The measurements of driving cycle for bus and car on A702 started from Tesco Metro at the junction of Colinton Road with Morningside Road and continued onto the junction of Comiston Road with Greenbank Crescent. The investigated A702 corridor is a single carriageway; it has two lanes on both directions, both of the lanes are for all type of vehicles, and there is no lane dedicated for buses. The length of the investigated corridor is approximately 1.0 mile (Figure 3.2). Table 3.3 shows the general characteristics of the corridor.

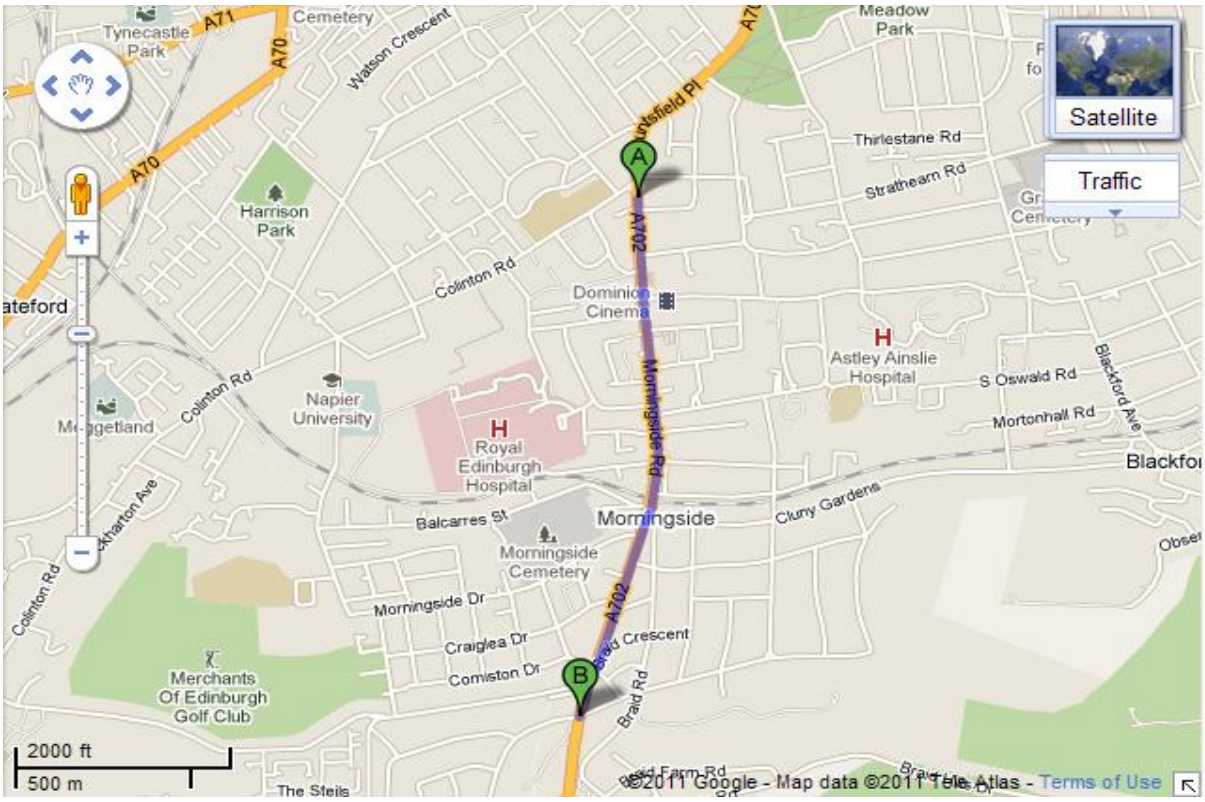


Figure 3.2: The A702 corridor (Source: Google Maps)

Table 3.3: The characteristics of the A702 Corridor

The corridors	**Number of bus stops**		**Number of Signalised junctions**		**Number of pedestrians crossing**		**Bus frequency**		**Number of bus routes**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
A702 (Mixed traffic)	7	5	5	5	5	5	36	36	6	6	Single carriageway	2	1.0 miles

The corridor is very busy during the peak hours, because the investigated part has six signalised junctions. The corridor has seven bus stops inbound and five bus stops outbound. It has five pedestrians crossing in both directions. The buses frequency are 36 inbound and 36 outbound. This corridor has 6 bus routes for each direction. According to Edinburgh City Council, the following Table 3.4 shows the traffic volume on the investigated part of the A702 corridor.

Table 3.4: Traffic flow on the A702 on three time periods (Source: Edinburgh City Council).

Time Period	Pedal Cycles	Motor Cycles	Cars & Taxis	Buses & Coaches	LGV's	HGV Rigid 2 Axles	HGV Rigid 3 Axles	HGV Rigid 4 Axles	HGV Artic 3,4 Axles	HGV Artic 5 Axles	HGV Artic 6 + Axles	Total
8.00-9.00	42	27	1,054	67	125	38	3	0	7	1	1	1,365
14.00-15.00	16.8	10.8	1054	167.5	125	95	7.5	0	17.5	2.5	2.5	1,499
PCU 8.00-9.00	35	10	789	61	140	27	2	0	3	0	1	1,068
PCU 14.00-15.00	14	4	789	152.5	140	67.5	5	0	7.5	0	2.5	1,182

3.4.1.3 Princes ST (from the beginning of Princes Street to the end of it), (this corridor is dedicated for buses and taxis only):

Princes Street is one of the major thoroughfares in central Edinburgh, Scotland, and its main shopping street. It is the southernmost street of Edinburgh's New Town, stretching around 1 mile (1.6 km) from Lothian Road in the west to Leith Street in the east. The street is mostly closed to private cars, with public transport given priority. The street has virtually no buildings on the south side, allowing panoramic views of the Old Town, Edinburgh Castle, and the valley between. The measurements of driving cycle for bus only on Princes ST started from the beginning of Princes St to the end of it. The Princes ST corridor is a dual carriageway; it has two lanes on both directions. This corridor is dedicated for buses and taxis only, and no other types of vehicles are allowed in Princes ST. The length of the investigated corridor is approximately 0.7 mile (Figure 3.3). Table 3.5 shows the general characteristics of the corridor.

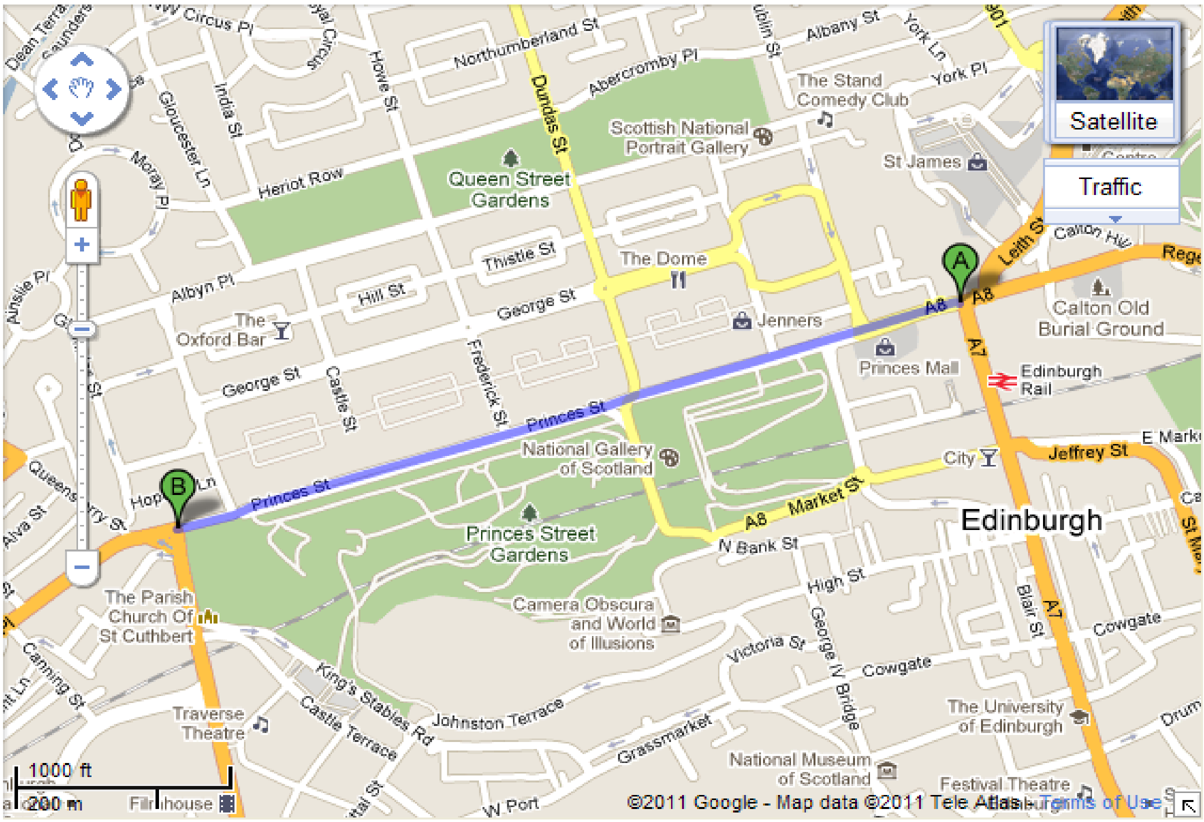


Figure 3.3: The Princes ST corridor (Source: Google Maps)

Table 3.5: The characteristics of the Princes Street Corridor

The corridors	Number of bus stops		Number of Signalised junctions		Number of pedestrians crossing		Bus frequency		Number of bus routes		Type of road	Number of lanes	Length of the corridor
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Princes St (Bus only)	9	12	7	7	4	4	156	156	29	29	Dual carriageway	2	0.7 miles

The corridor is very busy during the peak hours, because the investigated part has seven signalised junctions. The corridor has nine bus stops inbound and twelve bus stops outbound. It has four pedestrian crossings in both directions. The buses frequency are 156 inbound and 156 outbound. This corridor has 29 bus routes for each direction. According to Edinburgh City Council, the following Table shows the traffic volume on the investigated part of the Princes St corridor.

Table 3.6: Traffic flow on the Princes Street on three time periods (Source: Edinburgh City Council)

Time Period	Car & Taxis	Buses & Coaches	LGVs	HGV Rigid 2 Axles	HGV Rigid 3 Axles	HGV Rigid 4 Axles	HGV Artic 3,4 Axles	HGV Artic 5 Axles	HGV Artic 6 + Axles	Motor Cycles	Pedal Cycles	Total
8.00-9.00	2639	926	353	92	2	2	3	2	2	40	150	4211
14.00-15.00	2164	925	308	89	8	2	1	3	1	26	99	3626
PCU 8.00-9.00	2639	2315	882.5	230	5	5	7.5	5	5	16	60	6170
PCU 14.00-15.00	2164	2312.5	770	222.5	20	5	2.5	7.5	2.5	10.4	39.6	5556.5

3.4.2 Traffic corridors for traffic calming measure investigation in Edinburgh

Four traffic corridors were selected in this study to investigate the impacts of traffic calming measures in Edinburgh on traffic performance and on environmental issues. The routes were selected on the basis of the traffic calming measures implemented as follows:

Corridor 1 = Iona Street (20mph zone)

Corridor 2 = West Bryson Road (20mph zone)

Corridor 3 = Montgomery Street (20mph zone)

Corridor 4 = Polwarth Terrace (no traffic calming measures- Control corridor)

3.4.2.1 Corridor 1: Iona Street (20mph zone)

This corridor is located between the roads of Leith Walk and Easter Road as shown in Figure 3.4 and 3.5. It is the shortest of the traffic calming routes selected at 0.3miles. Although the route is not long it is a good addition for getting all round representative parameters because it incorporates three separate types of speed reducing measures combined to enforce the desired reduction in speed. They are speed cushions, speed humps and cobbled street surface. Each of the selected routes has its own method of reducing speed and with data samples gathered from all it will give an overall more representative insight into the broader picture of driving characteristics in Edinburgh's 20mph zones. Table 3.7 shows the general characteristics of the corridor.

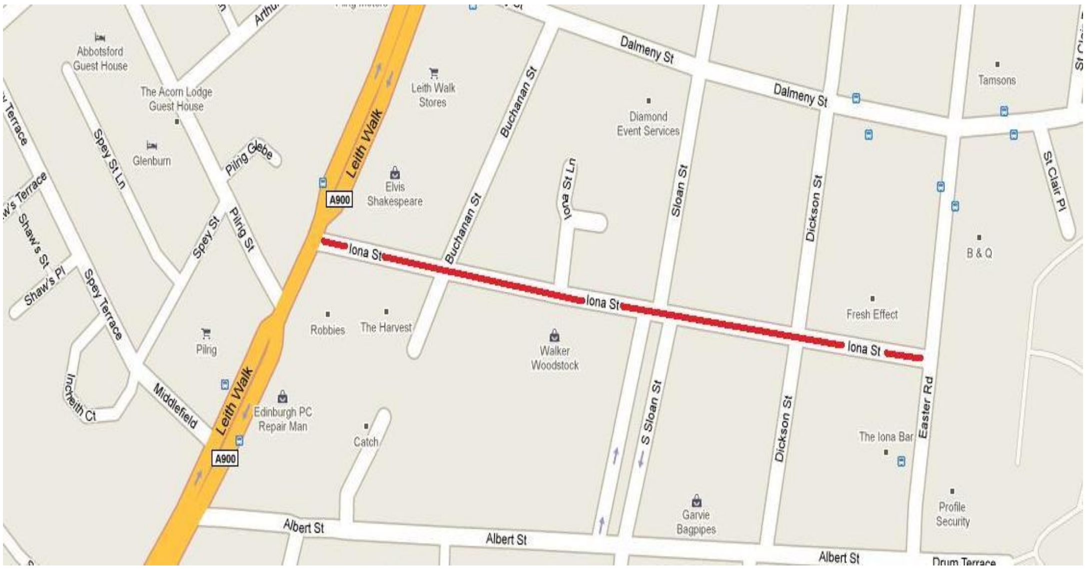


Figure 3.4: Iona Street (Source: Google Maps)

Figure 3.5: Iona Street with road humps

Table 3.7: The characteristics of the Iona Street corridor

The corridors	Number of T junctions		Number of + junctions		Number of raised junctions		Number of raised pedestrian crossing		Number of long humps		Number of cushion humps		Type of road	Number of lanes	Length of the corridor
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Iona Street	0	0	2	2	1	1	3	3	0	0	2	2	Single carriage way	1	0.3 miles

3.4.2.2 Corridor 2: West Bryson Road (20mph zone)

Corridor 2 is that of West Bryson road and Dundee Terrace which is located between the large roads of Colinton road and Slateford road and is a total of 0.4 miles in length. To access the commercial area of Fountain Park the 20mph zone offers an alternative to the traffic lights on the Angle Park Terrace road to the north west of Slateford Road as you look at Figure 3.6 and 3.7. This route was a student residential area that incorporated speed bumps as its method of speed reduction. The road was wide in nature and it ran past a playground situated in the adjacent park. Table 3.8 shows the general characteristics of the corridor.

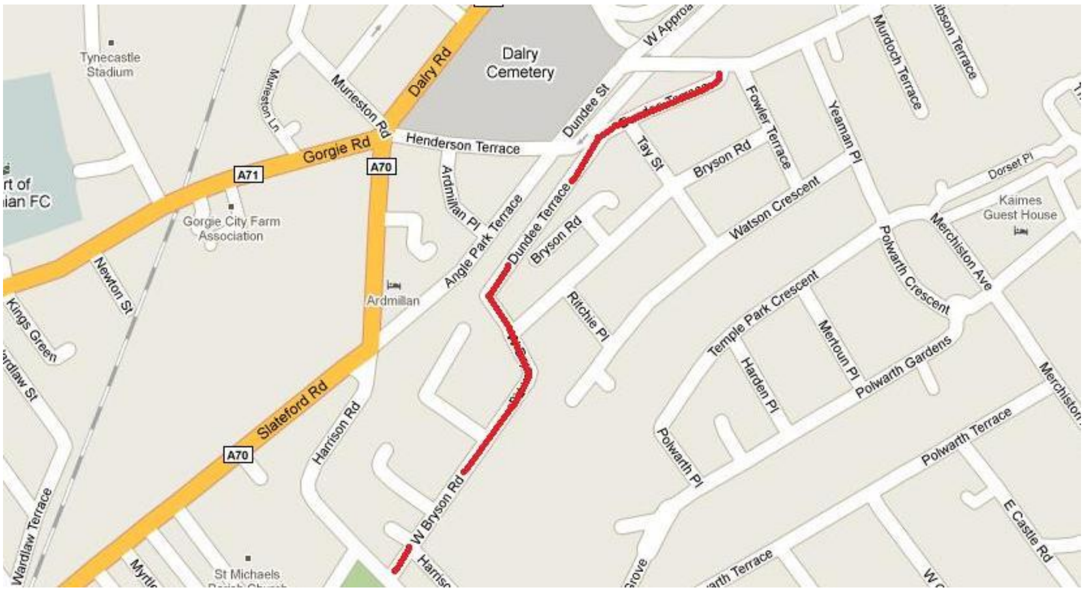


Figure3.6: West Bryson Road (Source: Google Maps)

Figure 3.7: A view of West Bryson Road

Table 3.8: The characteristics of the West Bryson Road Corridor

The corridors	**Number of T junctions**		**Number of + junctions**		**Number of raised junctions**		**Number of raised pedestrian crossing**		**Number of long humps**		**Number of cushion humps**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
West Bryson Road	0	0	0	0	4	4	3	3	2	2	0	0	Single carriageway	1	0.4 miles

3.4.2.3 Corridor 3: Montgomery Street (20mp zone)

Corridor 3 is located between the busy roads of Leith Walk and Easter Road and it is that of Montgomery Street is shown in Figure 3.8 and 3.9. It is the longest of the four routes selected at 0.5 miles, and there are a combination of speed reducing measures in place that comprises of speed humps and raised junctions. Table 3.9 shows the general characteristics of the corridor.

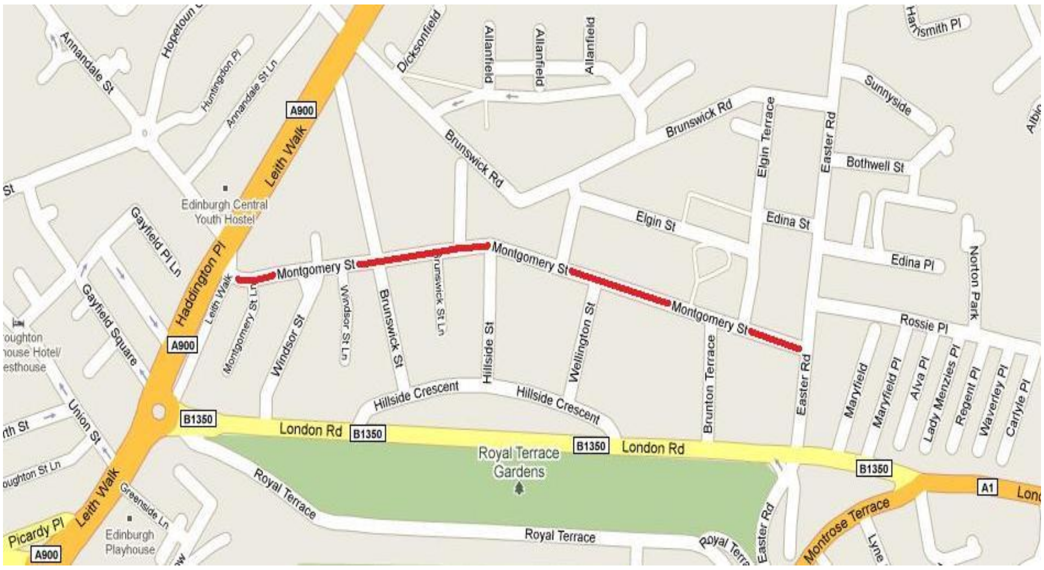


Figure 3.8: Montgomery Street (Source: Google Maps)

Figure 3.9: A view of Montgomery Street

Table 3.9: The characteristics of the Montgomery Street corridor

The corridors	**Number of T junctions**		**Number of + junctions**		**Number of raised junctions**		**Number of raised pedestrian crossing**		**Number of long humps**		**Number of cushion humps**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Montgomery Street	4	4	0	0	4	4	2	2	1	1	0	0	Single carriage way	1	0.5 miles

3.4.2.4 Corridor 4: Polwarth Terrace (no traffic calming measures- Control corridor)

This corridor was selected as the control corridor which the driving cycles of the other three traffic calming corridors would be compared to. It is a corridor of similar physical features which could plausibly be an alternative to the areas enforced by speed reducing measures. This corridor is similar to the 20mph zones in that it is bordered by parked cars along each side of its length and it is a residential area within walking distance of George Watsons School. Corridor 4 was a run carried out using the chase car technique to gather data on the real world driving patterns of drivers using that corridor as shown in Figure 3.10 and Figure 3.11. Table 3.10 shows the general characteristics of the corridor.

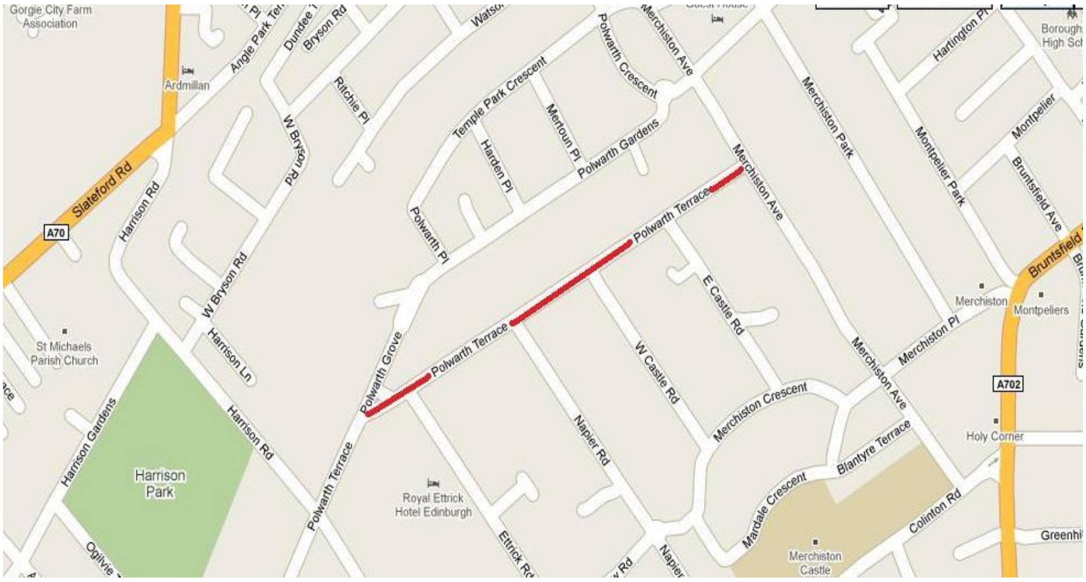


Figure 3.10: Polwarth Terrace (Source: Google Maps)

Figure 3.11: A view of Polwarth Terrace

Table 3.10: The characteristics of the Polwarth Terrace corridor

The corridors	Number of T junctions		Number of + junctions		Number of raised junctions		Number of raised pedestrian crossing		Number of long humps		Number of cushion humps		Type of road	Number of lanes	Length of the corridor
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Polwarth Terrace	6	6	0	0	0	0	0	0	0	0	0	0	Single carriage way	1	0.3 miles

3.4.3 Abu Dhabi traffic corridors

The two traffic corridors which were selected for the investigation of the development of Abu Dhabi driving cycle are discussed below. Both corridors have mixed traffic and do not operate bus lanes. It should be noted here that although bus lanes are not in operation in Abu Dhabi, it is one of the measures which have been considered by the local authorities there for implementation in the future. Therefore, this investigation is very relevant not only for comparison purposes but also to provide recommendations for policy makers in Abu Dhabi for future considerations of bus lanes.

3.4.3.1 Airport road (from Al Falah St with Airport Road junction to Mohamed Bin Khalifa St with Airport road junction)

Shaikh Rashid Bin Saeed Al Maktoum Road, popularly known as the Airport Road, is the most vital road in Abu Dhabi city. The measurements of driving cycle for bus and car on Airport Road started from the junction of Al Falah St with Airport Road to the junction of Mohamed Bin Khalifa St with Airport Road. The Airport Road corridor is a dual carriageway; it has four lanes on both directions for all type of vehicles, and there is no lane dedicated to buses. The length of the investigated corridor is approximately 1.0 mile (Figure 3.12). Table 3.11 shows the general characteristics of this corridor.

Figure 3.12: The Airport Road corridor (Source: Google Maps)

Table 3.11: The general characteristics of the Airport Rroad corridor

The corridors	Number of bus stops		Number of Signalised junctions		Number of pedestrians crossing		Bus frequency		Number of bus routes		Type of road	Number of lanes	Length of the corridor
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Airport Rd (Mixed traffic)	6	6	4	4	0	0	24	24	4	4	Dual carriageway	4	1.0 miles

The corridor is very busy during the peak hours, because the investigated part has four signalised junctions. The corridor has six bus stops inbound and six bus stops outbound. The pedestrians crossing are available on the junctions only. The buses frequency are 24 inbound and 24 outbound. This corridor has 4 bus routes for each direction.

3.4.3.2 Elektra Road (from Airport road with Electra St junction to Al Salam St with Electra St junction)

This corridor runs parallel to Hamdan Street and it's in the heart of Abu Dhabi city with many commercial shops on both side of it. The measurements of driving cycle for bus and car on Electra St started from the junction of the Airport Road with Electra St to the junction of Al Salam St with Electra St. The Electra St corridor is a dual carriageway; it has four lanes on both directions for all type of vehicles, and there is no lane dedicated for buses. The length of the investigated corridor is approximately 1.0 mile (Figure 3.13). Table 3.12 presents the general characteristics of the corridor.

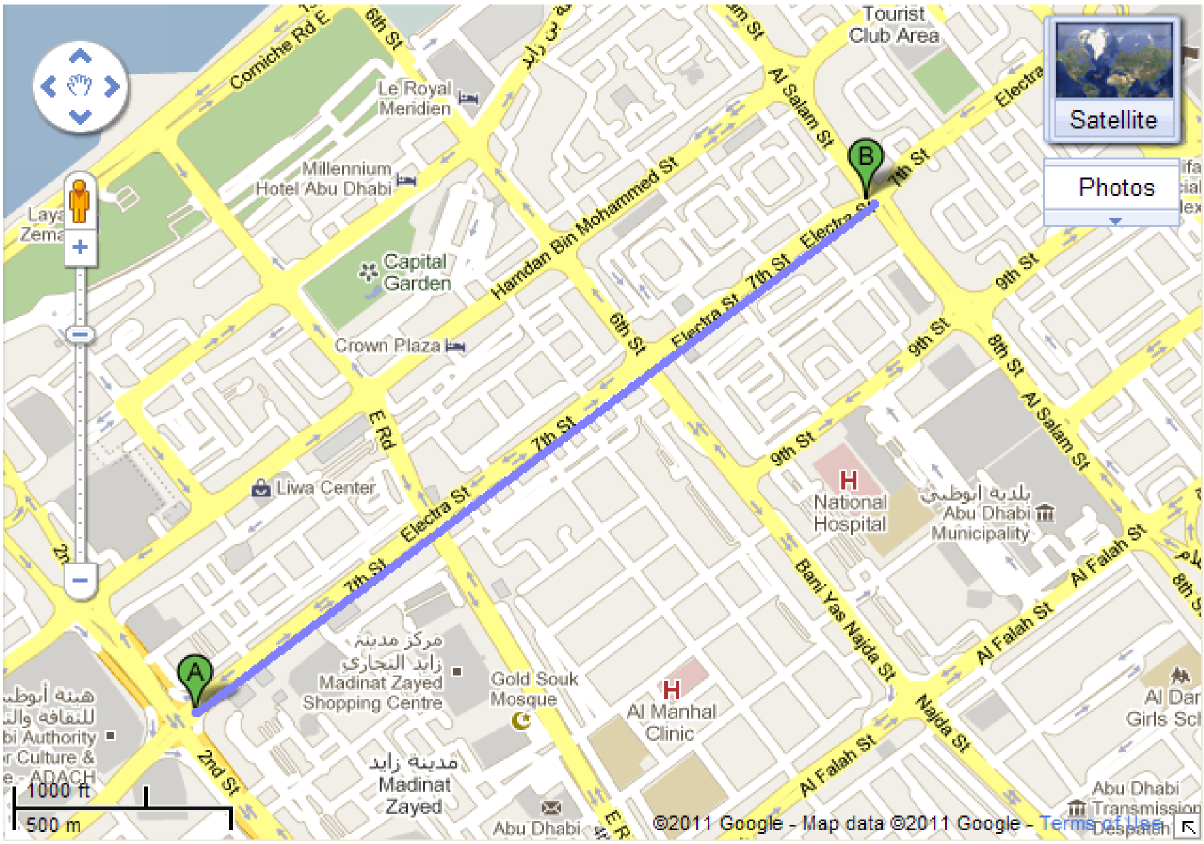


Figure 3.13: The Electra Street corridor (Source: Google Maps)

Table3.12: The general characteristics of the Elektra Street corridor

The corridors	Number of bus stops		Number of Signalised junctions		Number of pedestrians crossing		Bus frequency		Number of bus routes		Type of road	Number of lanes	Length of the corridor
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
Elektra Rd (Mixed traffic)	5	6	4	4	0	0	42	42	7	7	Dual carriageway	3	1.0 miles

The corridor is very busy during the peak hours, because the investigated part has four signalised junctions. The corridor has five bus stops inbound and six bus stops outbound. The pedestrian crossings are available on the junctions only. The buses frequency are 42 inbound and 42 outbound. This corridor has 7 bus routes for each direction.

CHAPTER 4

DATA COLLECTION METHODOLOGY

4.1 Introduction

The present study focuses on trips made by travellers on a number of traffic corridors in Edinburgh (UK) and in Abu Dhabi (UAE). The investigations include bus and car trips along the selected corridors, Firstly, three bus traffic corridors in Edinburgh were selected for this investigation. The second part of the study investigates four traffic corridors in Edinburgh with speed reduction measures for the assessment of these traffic calming measures and their impacts on speed, acceleration, and other driving modes using driving cycle analysis techniques. Thirdly, the driving cycles for two traffic corridors in Abu Dhabi were selected and investigated using the driving cycle techniques. See Chapters 3 and 5 for further discussions of the case studies and the development of the driving cycles for these corridors. In this chapter, the data collection is discussed. The selected corridors, piloting the data collection is firstly presented. The equipment used, the corridor and the assessment parameters are discussed.

4.2 The selected corridors- Edinburgh

The trips were investigated during both morning peak and off peak periods. It was attempted to select similar corridors in terms of traffic flow and other general characteristics. This is in order to be able to refer the differences in traffic characteristics only to differences in bus operation (i.e. with bus lane or without bus lanes). It was extremely difficult however; to identify two very similar traffic corridors in everything except in operating a bus lane; in particular where there is heavy traffic. As a result, most of the heavily congested traffic corridors have bus-lanes in operation, while the corridors which are lighter in terms of traffic volumes, could be operating mixed traffic. Therefore, it was not an easy task to identify similar traffic corridors which are different only in bus operation.

The most appropriately identified two corridors were the A7 (bus-lane corridor) and the A702 (mixed traffic corridor). These two corridors are quite similar in terms of traffic volume, number of bus routes, number of pedestrian crossings, number of signalised junctions as well as other geometrical characteristics. The third corridor which was considered in this study was a bus only corridor (Princes Street). This corridor has been dedicated to buses and to taxis only. Therefore, it represented an interesting opportunity for investigations of driving cycles on a bus-only traffic corridor. Therefore, driving cycle measurements were also carried out on Princes Street in Edinburgh.

In order to eliminate or at least minimise any possible errors due to any unsimilarities of the two corridors, it was also decided to carry out driving cycle measurements before 7.30 am (i.e. before the operation of the bus-lanes) on the selected traffic corridors. Table 4.1 below shows the general characteristics of the selected corridors.

Table 4.1: Characteristics of the selected bus traffic corridors

The corridors	**Number of bus stops**		**Number of Signalised junctions**		**Number of pedestrians crossing**		**Bus frequency**		**Number of bus routes**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
A7 (Bus lane)	7	8	6	6	6	6	57	57	10	10	Single carriageway	2	0.9 miles
A702 (Mixed traffic)	7	5	5	5	5	5	36	36	6	6	Single carriageway	2	1.0 miles
Princes St (Bus only)	9	12	7	7	4	4	156	156	29	29	Dual carriageway	2	0.7 miles

4.3 Pilot surveys

A pilot survey was carried out to assess and finalise the selection of the traffic corridors, the selection of data collection period, the procedures and any other considerations for the main survey. The pilot data collection exercise was carried out on two traffic corridors Gorgie Road (a bus-lane corridor) (Figure 4.1) and Gilmerton Road (mixed traffic corridor). Figure 4.2 shows a map of the corridor. Ten runs of measurements of driving cycle were carried out in each direction during three traffic periods (am peak, pm peak and afternoon off peak). It was found that the characteristics of driving cycles for the morning peak were very similar to those of the same evening peak, while the afternoon off peak traffic patterns were different. It was decided therefore, to collect the data during the morning peak and the afternoon off peak.

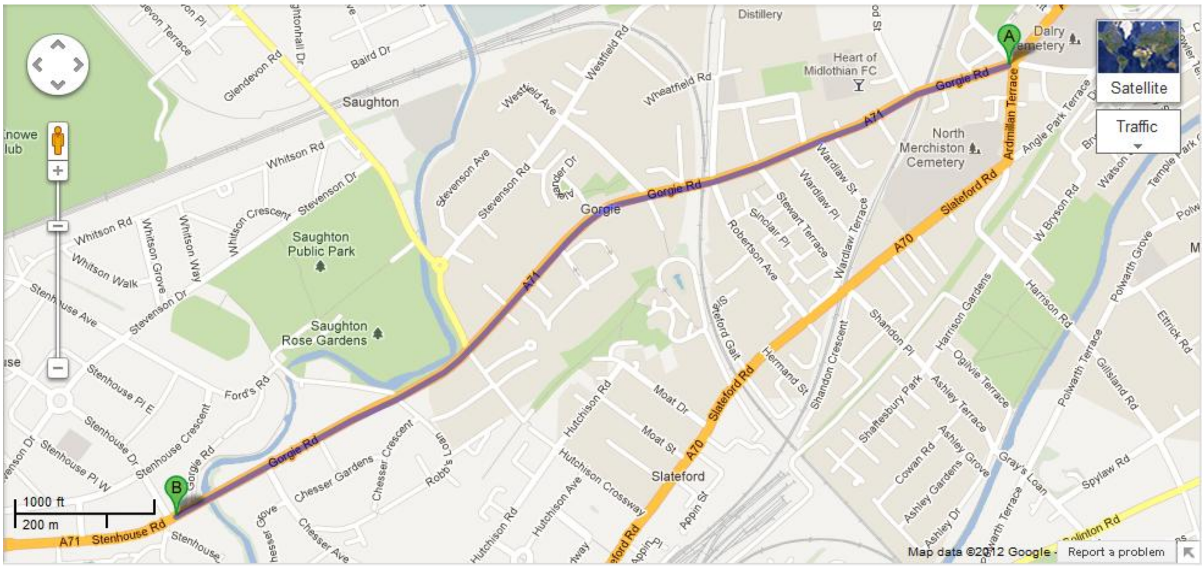


Figure 4.1: Gorgie Road (a bus-lane corridor) (Source: Google Maps)

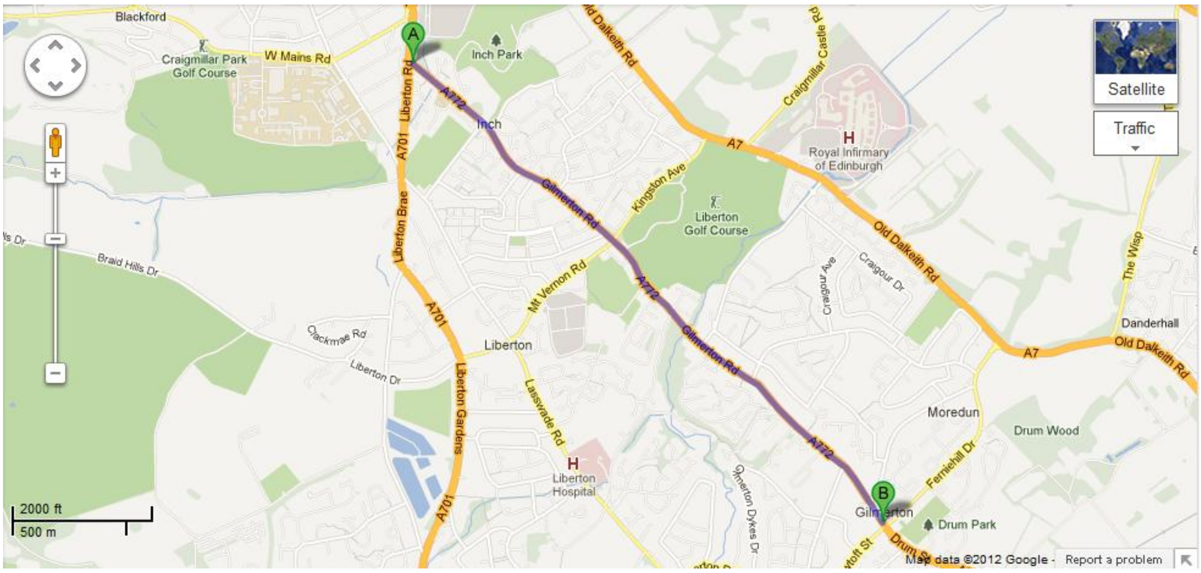


Figure 4.2: Gilmerton Road (mixed traffic corridor) (Source: Google Maps)

During the pilot surveys, it was also noted that the general characteristics of the two piloted corridors were quite different, not only from the point of view of the existence or otherwise of the bus corridors. It was decided therefore, to investigate the suitability of other traffic corridors for the main surveys. Finally, the two selected corridors for the main surveys were A702 and the A7. These were much more similar in the general characteristics and mainly different in terms of the availability of the bus lane.

4.5 Experimental equipment

In order to a develop data acquisition system for the driving cycle, the equipment which were used are discussed in the sections below. It should be mentioned here that this application is novel in the area of a bus context. It should however be acknowledged that technology for research is advancing constantly and that future research could, for example, also include video data.

4.6 Test vehicle

Data was collected on board via a private car for investigating the driving cycle. The car was a Honda Civic (2001), 1600cc engine size and automatic transmission, Table 4.2 shows the characteristics of the car used in the tests. The car was equipped with the Performance Box on the dashboard in order to collect the data.

Table 4.2: Characteristics of the private car used in the data collection

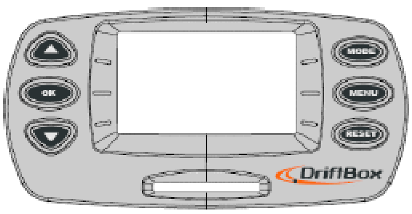
Model Year	Make	Engine Type (cc)	Drive's age (yrs)	Average annual mileage	Average Routine Maintenance
2001	Honda	1600	29	10,000	yearly

4.7 The performance box

The performance box (PB) device is a perfect tool for measuring vehicle or driver performance accurately. It is a high performance 10Hz Global Positioning System (GPS), which measures 10Hz logging of time, distance, speed, position, G-force, lap times and split times, as showed in (Figure 4.3)**.** The PB device has the ability to monitor vehicle speed, throttle position and mass air flow. The device automatically stores date and time. The GPS receives signals from the satellites and gives global location of the moving vehicle in second-to-second intervals. The data can then be downloaded to a desktop computer (PC) and analysed. PB uses MMC/SD flash memory card socket. The data is recorded into MMC flash card, which can be analysed in detail using the PC software provided. A rechargeable battery powers the PB. The Performance Box can also be connected to the USB port of a PC-compatible computer to download information stored on the memory card (Manual of Performance Box, 2008).

The private vehicle had two occupants, the driver and an assistant who recorded further information, such as, abnormal traffic or weather conditions, distances, as well as starting and ending times at each segment of the route. All these parameters were finalized during the pilot survey

PerformanceBox Keypad



▲	Used to show next screen, or to navigate menu.	MODE	Changes Mode.
OK	Select the menu item that is highlighted on the screen and used to show Score Code.	MENU	Accesses the relevant menu, or will exit from current menu.
▼	Used to show previous screen, or to navigate menu.	RESET	Resets totals, averages and peaks if held for 1.5s. Hold for 5s for global Reset.

Figure 4.3: Performance box keypad

During the testing, the Performance Box was kept on the dashboard of the car. Performance Box has a display screen mode that shows a large digital speed value and compass. In open conditions, Performance Box has a velocity accuracy of 0.1km/h, which is useful for checking the accuracy of your vehicle's speedometer. In this mode there are also Odometer and Height display screens. This display has a 'Point of Interest' facility, which alerts you as you approach the position of a point of interest such as a safety camera or service station. POI files can be created and edited for custom use. Performance Box can help measure the power developed by the car's engine, either at the wheels or flywheel. Having set the vehicle weight, results are calculated from the measurements taken by the fast GPS engine to give you useful guidelines to the car's brake horsepower or kilowatt output. Because these calculations are made from the GPS data rather than accelerometers, the results are likely to be more consistent and accurate.

4.8 Calibration of performance box

In any data collection equipment, the calibration of the measurement instrument is always crucial for the quality and reliability of the data. Since the all-driving data was required to be collected by the PB the calibration of the PB was crucial in order to collect meaningful data. The calibration process involved identification of accurate mile posts with fixed distance, clear roads during calibration process, clear weather for calibration test, clear instruction to driver to stop at marked line at mile post and authenticated distance between mile posts by regulatory authority. In this study a clear chalk mark was made on the ground on the test run. The PB was stabilised for 10 minutes at the beginning of each run. Data was recorded by professional person, while the driver carried out the driving manoeuvres at the desired speed and stopped at the marked line. Three test runs were made and correct start time and elapse time was noted using a stopwatch. The results showed that the error was within the acceptable limits of the equipment.

4.9 Data logging, coding and classification

Before analysing the database a systematic design of database was required for appropriate record keeping. Unique codes were generated which describe the routes, vehicle type, time and day and other characteristics as discussed below. The coding and classifications of the data were based on the major parameters involved in the driving cycle as shown in (Table 4.3).

After the data logging, the entered speed, acceleration, and decelerations were plotted against time data and was inspected visually for any abnormal characteristics. Sometimes the GPS readings had some sudden drop down in a few test runs while logging data. There could be other factors influencing the data collection including weather conditions, interferences of signals from high-rise walls, trees etc. which may affect the continuity of the data capturing process. Even the data capturing was discontinuous at few points. The Performance Box software tool prompts repair of the file by clicking on the Tools menu and choosing the File Repair option (Manual of Performance Box, 2008).

Table 4.3: Coding and classification for generating input files for driving cycle development

Parameters	Sub-category	Code	Notes
Codes for data		001-999	
Corridors	A7	1	Bus lane corridor
	A702	2	No bus lane corridor
	Princes St	3	Bus only corridor
	Corridor 1(Iona Street)	4	Speed calming corridor
	Corridor 2(West Bryson Road)	5	Speed calming corridor
	Corridor 3(Montgomery Street)	6	Speed calming corridor
	Corridor 4(Polwarth Terrace)	7	Speed calming corridor (control corridor)
	Airport Rd	8	Mixed traffic corridor
	Elektra Rd	9	Mixed traffic corridor
Time of travel	AM	1	6-30 a.m. - 7.30 a.m. peak
	AM	2	8.00 a.m. - 9.00 a.m. peak
	PM off-Peak	3	2.00 p.m. - 3.00 p.m.
	AM off-peak	4	11.00a.m – 12.00 p.m.
Vehicle	Car	1	
	Bus	2	
Direction	Inbound	1	
	Outbound	2	

The data acquisition system was followed as described in the previous section; it constitutes the database in which the types of vehicle, road types, time of travel, operating conditions etc. were stored. It is also assumed that the data collected via car and bus is representative of the ‘typical part of traffic stream’ of Edinburgh, because the car following technique was used. In addition, in case of buses, the drivers were driving their usual journeys, so their driving behaviour was assumed representative. The testing duration varied from 6.30 - 7.30 (early, RHM+), 8.00 - 9.00 (rush hours in the morning, RHM) and 14.00-15.00 (non-rush hours, NRH). Test runs were done ten times for each corridor and in each direction, a total number of 460 runs were finalised for analysis. Table 4.4 shows the breakdown of test runs over each of the routes during different hours. The largest percentage of trips was made in the morning.

Table 4.4: Duration of the test runs of different periods

Direction		Inbound			Outbound		
Road type		RHM	NRH	RHM+	RHM	NRH	RHM+
A7	Car	10	10	10	10	10	10
	Bus	10	10	10	10	10	10
A702	Car	10	10	0	10	10	0
	Bus	10	10	0	10	10	0
Princes St	Bus	10	10	0	10	10	0
Corridor 1	Car	0	20	0	0	0	0
Corridor 2	Car	0	20	0	0	0	0
Corridor 3	Car	0	20	0	0	0	0
Corridor 4	Car	0	10	0	0	0	0
Airport Rd	Car	10	10	0	10	10	0
	Bus	10	10	0	10	10	0
Elektra Rd	Car	10	10	0	10	10	0
	Bus	10	10	0	10	10	0
Total		90	150	20	90	90	20
Sub total			260			200	

Note: RHM= Rush Hour Morning; NRH = Non-Rush Hour; RHM+ = Early Rush Hour Morning (6.30-7.30 AM)

4.10 Analytical issues

This aim of this section is to discuss a selection of the assessment parameters that will be used to develop the driving cycles.

4.10.1 Assessment parameters for driving cycle development

Driving cycles can be created for each trip of a journey to measure the effectiveness of the TDM strategies in place. Using the driving cycles to assess the TDM, needs proper usage of specialized tools for measurements such as Performance Box, and driving tests among many others. The measurements can establish a relationship of demand and mode choice. In fact each measure will need implementable strategies to make it effective. Empirically, Kent et al. (1978) characterized the driving data by the speed-acceleration relative frequency as well as by overall parameters such as average speed and root mean square acceleration. Gandhi et al. (1983) used idling time, acceleration time, cruising time, deceleration time, total time, trip length, average speed and cruising speed to characterise the driving cycle for Delhi.

In Australia, measurements were done by Lyons et al. (1986) who used distance, mean speed, maximum speed, root mean square acceleration, mean positive acceleration, maximum and mean negative acceleration, stops per km, and positive kinetic energy to characterise the test runs. The corresponding synthetic run was then compared with original observations in Australia. The results showed that majority of the driving cycle assessment criteria in Australia were matched to within 10 % of the target value.

Tzeng et al., (1998) used a number of parameters including travel time, travel distance, average running speed, average acceleration of all acceleration phases provided acceleration *a* is greater than 0.1 ms^{-2}, average deceleration of all phases, mean length of driving periods, average number of acceleration and deceleration changes within one driving period, percentage of idling time where velocity V is less than 3 km/h, percentage of acceleration time, time percentage at constant speeds and percentage of deceleration time as assessment parameters to characterise and compare the Taipei motorcycle driving cycle.

Nine assessment criteria were used in the study by Tong et al. (1999) to characterize the driving pattern in the urban areas of Hong Kong. These criteria include:

(a) Average speed of the entire driving cycle
(b) Average running speed
(c) Average acceleration of all acceleration phases
(d) Average deceleration of all deceleration phases
(e) Mean length of driving period
(f) Time proportion of driving modes (idling, acceleration, cruise and deceleration)
(g) Average number of acceleration and deceleration changes within one driving period
(h) Root mean square acceleration
(i) Positive acceleration kinetic energy.

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

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

4.10.2 Data analysis methodology

The Data collected by performance box can be exported from the performance box software to excel format file for analysis. The mean value, standard deviation (SD) and coefficient of variations (COV) of those assessment parameters can then be estimated for each of the trip of selected routes. The COV values are to be calculated to show the variations in the performance of the test runs.

A further refining of the driving cycle was done by calculating the absolute sums of the relative error (Sj) then by selecting the driving cycle with minimum value of Sj. The relative error value for each of the parameters (Δ_k) is (see equation 4.1):

$$\Delta_k = \frac{(\bar{P} - P_{ij})}{P_{ij}} * 100 \qquad \text{equation 4.1}$$

Where k is an assessment parameter (k varies from 1 to 9) and Δ_k is the value of the relative error for parameter k, $\bar{P}$ is overall mean value of parameters. P_{ij} is a parameter with a value of a run i (between 1 and number of runs) and route category j. The absolute sum of the relative errors (Sj) was calculated for each route category type by summing up the individual relative error for a given route (Eq. 4.2):

$$S_j = \sum_{k=1}^{7} \Delta k \qquad \text{equation 4.2}$$

This current study adopts a similar approach to that suggested by Tong et al., (1999). In summary, a set of twelve assessment parameters have been used for the development of driving cycles for both Edinburgh and Abu Dhabi cities. The reason for this selection is that the parameters adopted are appropriate to use to investigate the impacts of any TDM measures and in specifically those measures of bus lanes and traffic calming measures.

Table 4.5: Assessment parameters for the driving cycle

Sr. No	Assessment parameters	Abbreviation	Units
1	Average trip duration	T	Seconds
2	Average speed of entire driving cycle	V	Km/hr
3	Mean length of driving period	L	Meters
4	Average acceleration of all acceleration phases	A	m/sec^{-2}
5	Average deceleration of all deceleration phases	D	m/sec^{-2}
6	Percentage time spent in driving modes for acceleration	Pa	%
7	Percentage time spent in driving modes for deceleration	Pd	%
8	Percentage time spent in driving modes for idling	Pi	%
9	Percentage time spent in driving modes for cruising	Pc	%
10	Standard deviation	Sd	
11	Coefficient of variation	Cov	
12	Sum of absolute relative error	Sj	

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

Equations 4.1 & 4.2 were used to calculate the relative error values and the absolute sum of the relative errors.

4.11 Summary

The investigation of driving cycle as a tool to assess a number of TDM measures has been carried out in this research, which have been influenced by the Edinburgh context, i.e. there are many other TDM measures that could have been considered if suitable case studies were available. There are many methods available to derive the driving cycle. In this chapter, a practical approach is devised to collect data for the development of driving cycles in Edinburgh and Abu Dhabi cities. The performance box was calibrated and used to ensure quality of data and issues related to collection of driving data has been discussed. This is in order to a develop data acquisition system for the driving cycle. It should be mentioned here that this application is novel in the area of a bus context. It should also be acknowledged that technology for research is advancing constantly and that future research could, for example, also include video data.

Eight routes were selected and trips were made along these routes to collect driving data using the performance box. To derive the driving cycle 12 sets of assessment criteria were assessed and analysed. Data analysis for deriving driving cycle has been discussed in Chapters 5-7.

CHAPTER 5

RESULTS AND PRELIMINARY ANALYSIS

5.1 Introduction

This chapter presents results and preliminary analysis obtained from monitoring and measuring the performance of cars and buses on the selected corridors in this study. These include presenting the results obtained from the assessment of the bus traffic corridors and the traffic calming corridors in Edinburgh as well as the traffic corridors in Abu Dhabi. This data is used for the development of the driving cycle as discussed in Chapter four.

5.2 Results and preliminary analysis of the "bus traffic corridors" in Edinburgh

As discussed earlier in Chapter four, data was collected for the buses and cars on the "bus traffic corridors" in Edinburgh, "traffic calming corridors" in Edinburgh as well as for buses and cars on the "traffic corridors" in Abu Dhabi. Only bus data was collected for the "bus only corridor" in Edinburgh.

The results of the characteristics of the buses and cars on the bus traffic corridors in Edinburgh are discussed in this section. The measurements were carried out for each of the three corridors during peak (8.00-9.00 am**)** and off-peak (2.00-3.00 pm**)** hours of traffic as well as before the bus lane operation (6.30-7.30am**)**. The measurements were repeated for both directions of traffic flow on each corridor as well (that is inbound and outbound). Table 5.1 below presents the general characteristics of the bus traffic corridors in Edinburgh. These characteristics are discussed below. These characteristics include the average journey time, average journey speed, average journey length, average journey acceleration, average journey deceleration, standard deviation and coefficient of variation (COV).

Table 5.1: General characteristics of the bus traffic corridors in Edinburgh

Corridors	Time	Mode	Direction	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	Average Acc (m/sec^2)	Average Dec (m/sec^2)
A7 (bus lane corridor)	8.00-9.00 am	Car	Inbound	250.022	21.353	1446.969	0.995	-1.121
			SD	41.543	3.599	51.437	0.241	0.235
			COV	0.166	0.168	0.035	0.243	-0.21
			Outbound	232.555	23.401	1480.22	0.867	-0.925
			SD	41.445	3.481	121.899	0.167	0.204
			COV	0.178	0.148	0.082	0.193	-0.22
		Bus	Inbound	385.72	12.273	1297.961	1.035	-1.782
			SD	51.834	1.599	100.396	0.244	1.107
			COV	0.134	0.13	0.077	0.236	-0.621
			Outbound	354.2	15.29	1482.013	0.792	-1.075
			SD	50.565	1.998	68.441	0.044	0.303
			COV	0.142	0.13	0.046	0.056	-0.282
	2.00-3.00 pm	Car	Inbound	286.18	18.79	1444.447	0.8795	-1.0317
			SD	53.547	3.793	30.327	0.11	0.408
			COV	0.187	0.201	0.02	0.126	-0.395
			Outbound	291.92	19.245	1531.861	0.85	-0.955
			SD	42.681	2.816	50.761	0.175	0.239
			COV	0.146	0.146	0.033	0.206	-0.25
		Bus	Inbound	419.1	11.794	1313.907	0.891	-1.308
			SD	57.569	2.019	65.228	0.15	0.632
			COV	0.137	0.171	0.049	0.169	-0.483
			Outbound	365.23	14.759	1474.767	0.836	-1.273
			SD	50.458	2.049	88.276	0.09	0.588
			COV	0.138	0.138	0.059	0.108	-0.462
	6.30-7.30 am	Car	Inbound	163.044	31.946	1436.173	0.937	-0.919
			SD	15.161	3.109	44.025	0.291	0.289
			COV	0.092	0.097	0.03	0.31	-0.314
			Outbound	169.922	32.39	1489.863	1.029	-2.315
			SD	23.613	7.363	142.87	0.633	4.311
			COV	0.138	0.227	0.095	0.615	-1.862
		Bus	Inbound	189.085	17.638	931.191	1.372	-6.111
			SD	36.519	2.902	237.273	0.466	1.258
			COV	0.193	0.164	0.254	0.339	-0.205
			Outbound	259.788	19.989	1396.928	0.863	-2.03
			SD	56.517	3.561	110.833	0.061	1.628
			COV	0.217	0.178	0.079	0.07	-0.802
A702 (no bus lane corridor)	8.00-9.00 am	Car	Inbound	253.68	20.545	1422.66	0.968	-1.644
			SD	31.004	4.072	161.444	0.129	0.854
			COV	0.122	0.198	0.113	0.133	-0.519
			Outbound	276.122	22.051	1650.357	0.857	-1.384
			SD	40.654	3.494	67.514	0.136	0.722
			COV	0.147	0.158	0.04	0.159	-0.522
		Bus	Inbound	399.24	13.333	1422.844	1.07	-1.812
			SD	90.182	2.856	159.973	0.233	0.945
			COV	0.225	0.214	0.112	0.217	-0.521
			Outbound	350.99	16.401	1563.981	1.07	-3.242
			SD	82.059	2.409	249.507	0.238	2.523
			COV	0.233	0.146	0.159	0.222	-0.778
	2.00-3.00 pm	Car	Inbound	259.37	22.046	1568.821	0.895	-1.07
			SD	30.915	2.802	91.667	0.061	0.232
			COV	0.119	0.127	0.058	0.069	-0.217
			Outbound	318.82	19.234	1622.052	1.021	-2.091
			SD	78.398	4.51	146.361	0.313	1.607
			COV	0.245	0.234	0.09	0.306	-0.768
		Bus	Inbound	405.41	12.964	1451.403	1.109	-1.967
			SD	47.014	1.589	164.5	0.152	0.813
			COV	0.115	0.122	0.113	0.137	-0.413
			Outbound	358.811	16.758	1646.576	1.055	-2.041
			SD	55.017	2.302	125.77	0.17	1.099
			COV	0.153	0.137	0.076	0.161	-0.538

Princes St (bus only corridor)	**8.00-9.00 am**	**Bus**	**Inbound**	286.52	14.426	1091.004	0.803	-0.809
			SD	64.289	3.699	68.25	0.093	0.118
			COV	0.224	0.256	0.062	0.116	-0.146
			Outbound	244.866	15.414	1023.532	0.797	-0.885
			SD	62.414	2.528	219.771	0.076	0.867
			COV	0.254	0.164	0.214	0.096	-0.979
	2.00-3.00 pm	**Bus**	**Inbound**	235.31	16.741	1082.989	0.819	-0.836
			SD	26.823	1.962	53.206	0.036	0.061
			COV	0.113	0.117	0.049	0.044	-0.073
			Outbound	223.855	19.44	1206.023	0.838	-0.873
			SD	18.209	1.055	89.772	0.065	0.103
			COV	0.081	0.054	0.074	0.078	-0.117

5.2.1 Average journey time

The average journey times for the bus-lane, mixed-lane and bus-only corridors have been calculated and analysed. Firstly, for the bus-lane corridor (A7), the average journey times during peak hours for buses were 385.72 sec (inbound) and 354.2 sec (outbound), and for cars were 250.022 sec (inbound) and 232.555 sec (outbound). During off-peak hours, average journey times for buses were 419.1 sec (inbound) and 365.23 sec (outbound), and for cars were 286.18 sec (inbound) and 291.92 sec (outbound). During 6.30-7.30 am, average journey times for buses were 189.085 sec (inbound) and 259.788 sec (outbound), and for cars were 163.044 sec (inbound) and 169.922 sec (outbound).

For the mixed-traffic corridor (A702), the average journey times during peak hours for buses were 399.24 sec (inbound) and 350.99 sec (outbound), and for cars were 253.68 sec (inbound) and 276.122 sec (outbound). During off-peak hours, average journey times for buses were 405.41 sec (inbound) and 358.811 sec (outbound), and for cars were 259.37 sec (inbound) and 318.82 sec (outbound).

For the bus-only corridors (Princes Street), the average journey times during peak hours for buses were 286.52 sec (inbound) and 244.866 sec (outbound). During off-peak hours, average journey time for buses were 235.31 sec (inbound) and 223.855 sec (outbound).

Figure 5.1 shows that the travel time is significantly higher for buses even on corridors with bus lanes during all times. This implies that the bus lanes are not functioning as anticipated. It is normally expected that the dedicated bus lane would improve travel time of buses as compared to other modes in order to make public transport more attractive. However, the results show that the bus lanes have travel times more than 1.5 times higher than the travel times of cars on average. Bus lanes use a dedicated portion of road area and are expected to provide considerable improvements in terms of travel time for them to be deemed beneficial.

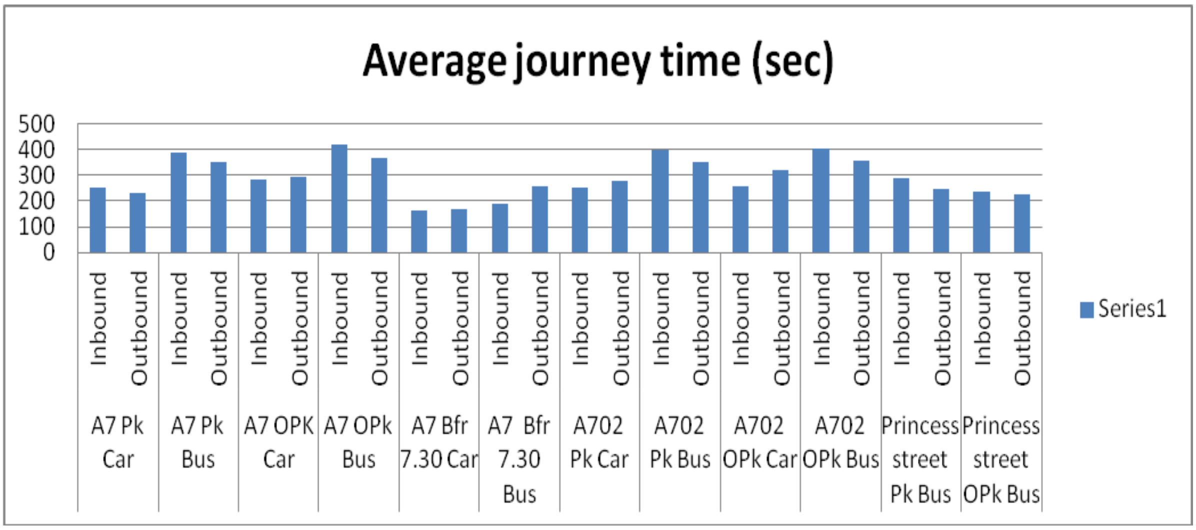


Figure 5.1: The total travel time during the period of data collection for each of the mode on different corridors

But, the results show a different picture. The difference of travel time between cars and buses for bus lane roads and the ones without them are almost 1.5 higher for buses. This proves that the provision of a bus lane does not necessarily improve the conditions of public transport. On the contrary, there should be careful consideration about the geometry and traffic structure in addition to volumes. It has been observed that at signalised intersections, buses have to mix with other traffic and thus time gained via bus lane is not only lost but it delays the overall operation. Furthermore, parked cars also reduce the road capacity and disrupt other TDM measures.

5.2.2 Journey speed

The average journey speeds for the bus-lane, mixed-lane and bus-only lane corridors have also been calculated and analysed. Firstly, for the bus-lane corridor (A7), the average journey speeds during peak hours for buses were 12.273 km/hr (inbound) and 15.29 km/hr (outbound), and for cars were 21.353 km/hr (inbound) and 23.401 km/hr (outbound). During off-peak hours, average journey speeds for buses were 11.794 km/hr (inbound) and 14.759 km/hr (outbound), and for cars were 18.79 km/hr (inbound) and 19.245 km/hr (outbound). During 6.30-7.30 am, average journey speeds for buses were 17.638 km/hr (inbound) and

19.989 km/hr (outbound), and for cars were 31.946 km/hr (inbound) and 32.39 km/hr (outbound).

For the mixed-traffic corridor (A702), the average journey speeds during peak hours for buses were 13.333 km/hr (inbound) and 16.401 km/hr (outbound), and for cars were 20.545 km/hr (inbound) and 22.05 km/hr 1 (outbound). During off-peak hours, average journey speeds for buses were 12.964 km/hr (inbound) and 16.758 km/hr (outbound), and for cars were 22.046 km/hr (inbound) and 19.234 km/hr (outbound).

For the bus-only corridors (Princes Street), the average journey speeds during peak hours for buses were 14.426 km/hr (inbound) and 15.414 km/hr (outbound). During off-peak hours, average journey speeds for buses were 16.741 km/hr (inbound) and 19.44 km/hr (outbound).

Figure 5.2 shows the speeds of cars and buses during the period of data collection on different corridors. The figure shows that the speed of buses is significantly lower than cars on all types of roads during all times. The speed of buses on bus only road, and bus lane roads is almost the same as that on mixed traffic roads. It depicts again that the bus lanes are not functioning properly. It would be expected that the dedicated bus lane should improve the overall bus speeds as compared to the buses on mixed traffic roads in order to improve public transport operations and making it attractive. However, the results show that the bus lanes have speeds less than half of that of cars on average. Although the speeds of bus only roads are better as compared to mixed traffic roads, bus lane roads are lowest of them all. The reason here again could be the mixing of traffic at junctions and long queues at the bus stops. This also proves that the provision of a bus lane does not necessarily improve the conditions of public transport. On the contrary, there should be careful consideration about the geometry and traffic structure in addition to volumes.

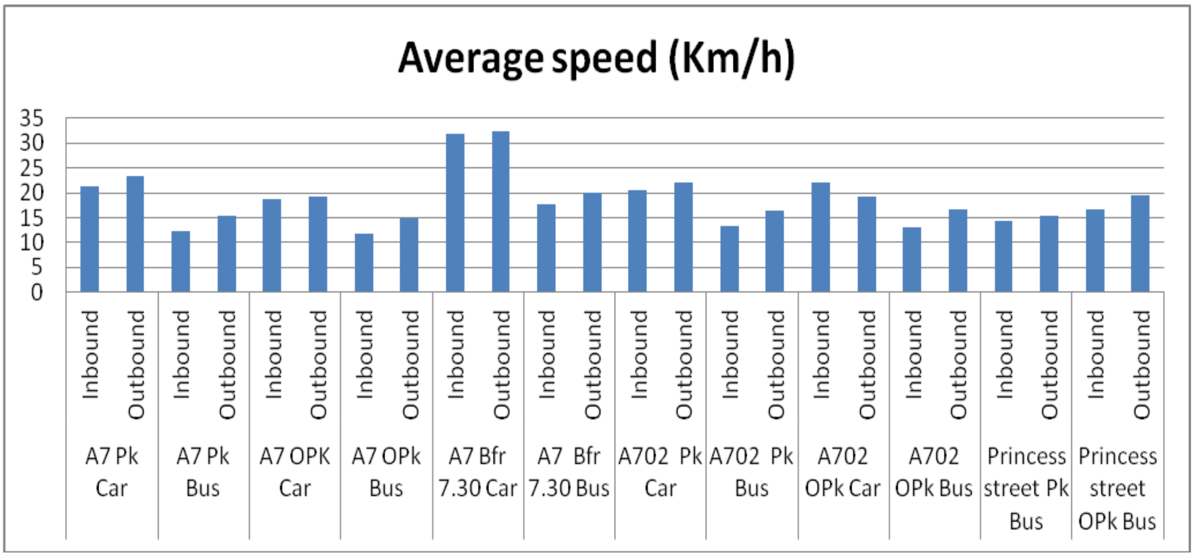


Figure 5.2: The average speeds of cars and buses during the period of data collection on different corridors

5.2.3 Average journey length

The average journey lengths for the bus-lane corridor (A7), during peak hours for buses were 1297.961 meter (inbound) and 1482.013 meters (outbound), and for cars was 1446.969 meters (inbound) and 1480.22 meters (outbound). During off-peak hours, average journey length for buses was 1313.907 meters (inbound) and 1474.767 meters (outbound), and for cars was 1444.447 meters (inbound) and 1531.861 meters (outbound). During 6.30-7.30 am, average journey length for buses was 931.191 meters (inbound) and 1396.928 meters (outbound), and for cars was 1436.173 meters (inbound) and 1489.863 meters (outbound).

For the mixed-traffic corridor (A702), the average journey length during peak hours for buses was 1422.844 meters (inbound) and 1563.981 meters (outbound), and for cars was 1422.66 meters (inbound) and 1650.357 meters (outbound). During off-peak hours, average journey length for buses was 1451.403 meters (inbound) and 1646.576 meters (outbound), and for cars was 1568.821 meters (inbound) and 1622.052 meters (outbound).

For the bus-only corridors (Princes Street), the average journey length during peak hours for buses was 1091.004 meters (inbound) and 1023.532 meters (outbound). During off-peak hours, average journey length for buses was 1082.989 meters (inbound) and 1206.023 meters (outbound).

Figure 5.3 shows the average length of journey during the period of data collection on different corridors. This can be used to compare the sections under analysis.

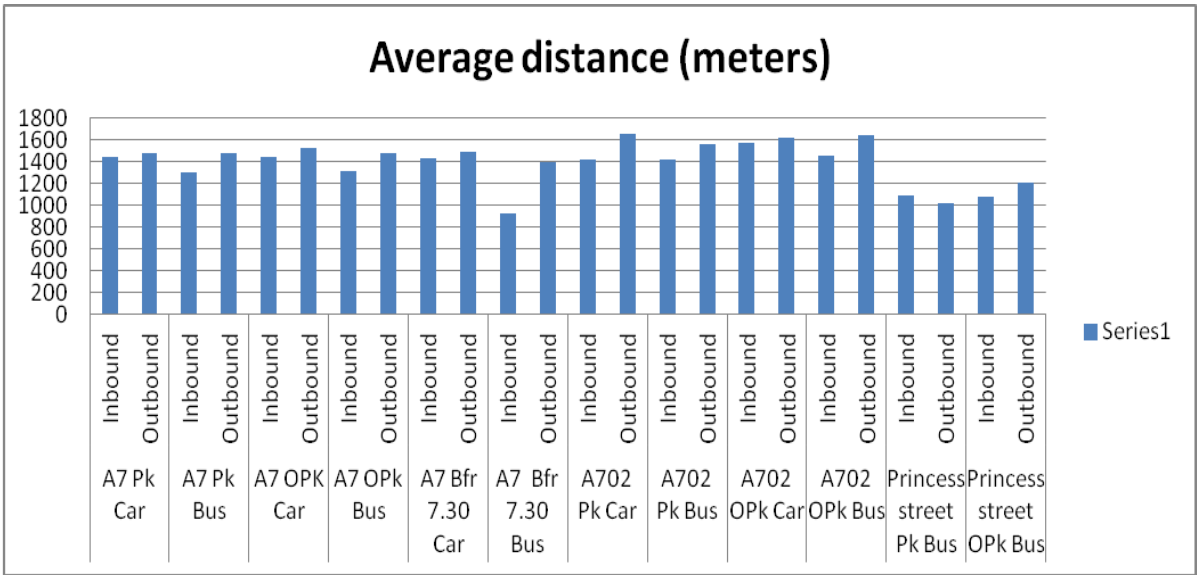


Figure 5.3: The length during the period of data collection on different corridors

The average length of the section for inbound bus in early rush hour morning seems little different from the rest of the categories as the data collected for this section used smaller length of the section. However this does not create any problem with the overall results and they were considered adequate for further analysis. The section for the bus only road is also little bit shorter but again the results show that the collected data was enough for further analysis (reasons for this difference in length ie. Location of bus stops).

5.2.4 Average journey acceleration

The average journey acceleration on the bus lane corridor (A7), during peak hours for buses was 1.035 m/sec^2 (inbound) and 0.792 m/sec^2 (outbound), and for cars was 0.995 m/sec^2 (inbound) and 0.867 m/sec^2 (outbound). During off-peak hours, the average journey acceleration, on the bus lane corridor (A7) for buses was 0.891 m/sec^2 (inbound) and 0.836 m/sec^2 (outbound), and for cars was 0.879 m/sec^2 (inbound) and 0.85 m/sec^2 (outbound). During 6.30-7.30 am, the average journey acceleration on the bus lane corridor (A7) for buses was 1.372 m/sec^2 (inbound) and 0.863 m/sec^2 (outbound), and for cars was 0.937 m/sec^2 (inbound) and 1.029 m/sec^2 (outbound).

Whereas the average journey acceleration on the mixed-traffic corridor (A702), during peak hours for buses was 1.07 m/sec^2 (inbound) and 1.07 m/sec^2 (outbound), and for cars was 0.968 m/sec^2 (inbound) and 0.857 m/sec^2 (outbound). During off-peak hours, the average journey acceleration, on the mixed-traffic corridor (A702) for buses was 1.109 m/sec^2 (inbound) and 1.055 m/sec^2 (outbound), and for cars was 0.895 m/sec^2 (inbound) and 1.021 m/sec^2 (outbound).

For the bus-only corridors (Princes Street), the average journey acceleration on the bus-only corridor, during peak hours for buses was 0.803 m/sec^2 (inbound) and 0.797 m/sec^2 (outbound). During off-peak hours, the average journey acceleration, on the bus-only corridor for buses was 0.819 m/sec^2 (inbound) and 0.838 m/sec^2 (outbound).

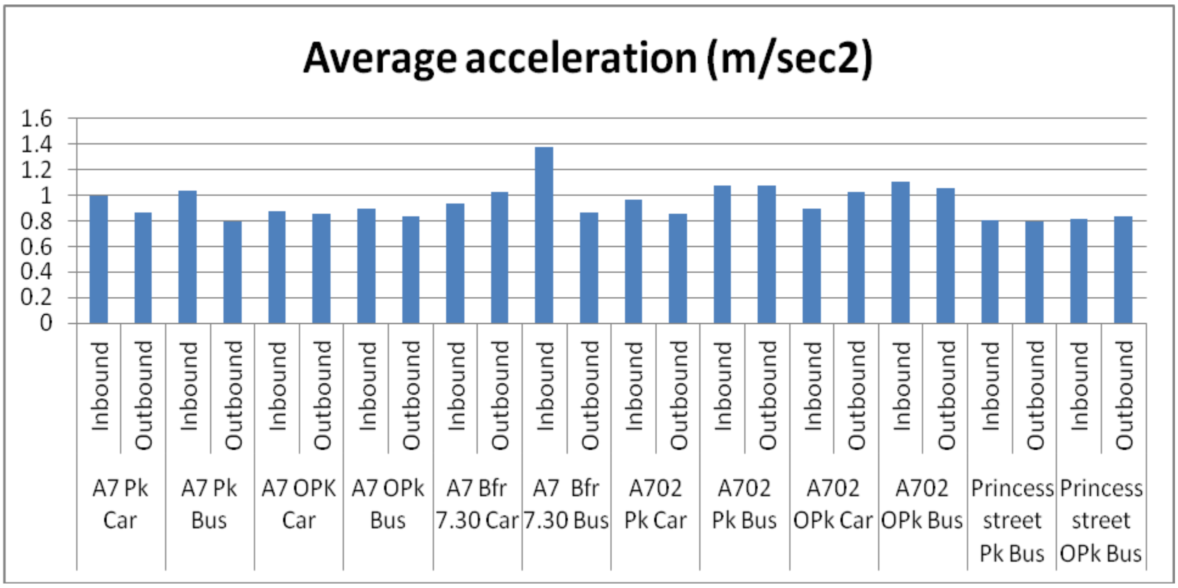


Figure 5.4: The total average journey acceleration during the period of data collection for each of the mode on different corridors

Figure 5.4 shows that the average journey acceleration for buses is significantly higher for buses even on roads with bus lanes during all times. It depicts that the bus lanes are not functioning properly. However, the situation in bus only roads is different which have around the same proportion of acceleration phases as cars on other routes. Here again it should be noted that bus lanes use a dedicated portion of road area and are expected to provide considerable improvements in terms of efficiency for their appraisal but, the results show a different picture. This proves that the provision of a bus lane does not necessarily improve the conditions of public transport. It has been observed that at signalised intersections, buses have to mix with other traffic and thus performance is compromised in the event of merging with other traffic. Furthermore, parked cars also reduce the road capacity and disrupt other TDM measure.

5.2.5 Average journey deceleration

The average journey deceleration on the bus lane corridor (A7), during peak hours for buses was -1.782 m/sec^2 (inbound) and -1.075 m/sec^2 (outbound), and for cars was -1.121 m/sec^2 (inbound) and -0.925 m/sec^2 (outbound). During off-peak hours, the average journey deceleration, on the bus lane corridor (A7) for buses was -1.308 m/sec^2 (inbound) and -1.273 m/sec^2 (outbound), and for cars was -1.0317 m/sec^2 (inbound) and -0.955 m/sec^2 (outbound). During 6.30-7.30 am, the average journey deceleration on the bus lane corridor (A7) for buses was -6.111 m/sec^2 (inbound) and -2.03 m/sec^2 (outbound), and for cars was -0.919 m/sec^2 (inbound) and -2.315 m/sec^2 (outbound).

Whereas the average journey deceleration on the mixed-traffic corridor (A702), during peak hours for buses was -1.812 m/sec^2 (inbound) and -3.242 m/sec^2 (outbound), and for cars was -1.644 m/sec^2 (inbound) and -1.384 m/sec^2 (outbound). During off-peak hours, the average journey deceleration, on the mixed-traffic corridor (A702) for buses was -1.967 m/sec^2 (inbound) and -2.041 m/sec^2 (outbound), and for cars was -1.07 m/sec^2 (inbound) and -2.091 m/sec^2 (outbound).

For the bus-only corridors (Princes Street), the average journey deceleration on the bus-only corridor, during peak hours for buses was -0.809 m/sec^2 (inbound) and -0.885 m/sec^2 (outbound). During off-peak hours, the average journey deceleration, on the bus-only corridor for buses was -0.836 m/sec^2 (inbound) and -0.873 m/sec^2 (outbound).

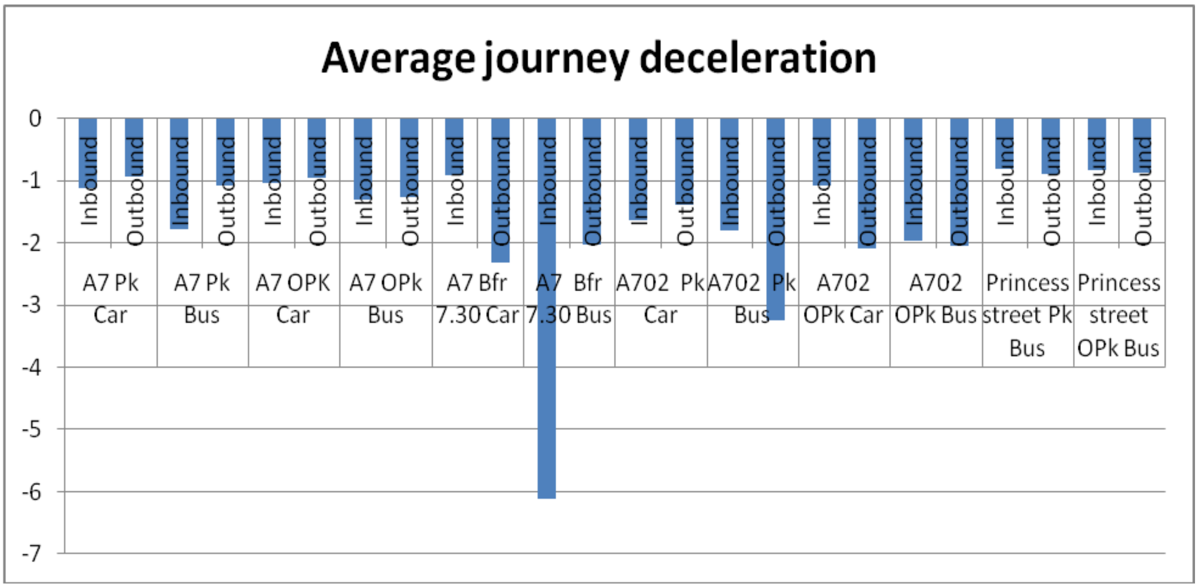


Figure 5.5: The total average journey deceleration during the period of data collection for each of the mode on different corridors

Figure 5.5 shows that the average journey deceleration for buses is significantly lower for buses even on roads with bus lanes during all times. This means that buses are spending more times on either idling/cruising or accelerating. It depicts that the bus lanes playing on average at lower speeds and hence there is not much proportion of decelerating as compared to cars which have on average higher speeds. The deceleration phases, on the other hand, on the bus only routes is almost 20% of the time. This means that the conditions there are relatively better as compared to bus lane roads. This shows that bus lanes again are not functioning properly.

5.3 Results and preliminary analysis of speed calming measures in Edinburgh

This section investigates the general characteristics of traffic along traffic calming corridors. Speed calming measures have been associated in the literature with a reduction in speed and improvements in safety aspects in urban areas. Höglund and Niittymaki (1999) studied the effect of speed humps during peak and non-peak hours using the speed profiles of traffic simulation and computerized emission calculations and found that speed humps are responsible for an increase in HC, CO, NOx emissions and also an increase in the fuel consumption, compared to a no-speed hump alternative for a 50 km/h speed limit scenario (Höglund and Niittymäki, 1999). Boulter et al., (2001) also found that traffic calming measures have similar impacts on emissions. Boulter and his colleagues also developed a methodology for constructing the driving cycles of speed hump measures. The study utilized the measurement of the speed profiles of a large number of vehicles using a roadside Light Detection and Ranging (LIDAR) system. Also, Daham et al. (2005) by simulating braking and acceleration events to mimic speed humps by driving a normal road using an on-road emission measurement device, found that speed humps increase HC, CO, NOx, and CO2 emissions by 148%, 117%, 195%, and 90%. For the current study, the data collected while driving over speed calming corridors was investigated and analysed.

Three corridors were selected with different traffic calming measures and the fourth corridor has no speed reduction measures and was used as a control corridor. The traffic corridors are listed below:

Corridor 1: Iona Street (20 mph zone with speed cushions, speed humps and cobbled street surface)
Corridor 2: West Bryson Road (20 mph zone with speed humps)
Corridor 3: Montgomery Street (20 mph zone with speed humps and raised junctions)
Corridor 4: Polwarth Terrace (20 mph zone with no speed humps). This corridor was considered as the control corridor.

Tables 5.2 below show summary results of traffic performance and characteristics over these four selected corridors.

Table 5.2: Summary characteristics of traffic performance on traffic calming corridors

Corridors	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	Average Acc (m/sec^2)	Average Dec (m/sec^2)
Corridor 1	58.59	24.128	392.0356	0.55515	-0.5283
SD	9.621407	1.615757	64.5323	0.08491065	0.080033611
COV	0.164216	0.066966	0.164608	0.152950823	-0.151492734
Corridor 2	97.735	23.87025	643.9516	0.72055	-0.73475
SD	9.202189	2.148803	21.68666	0.083938872	0.090841606
COV	0.094154	0.09002	0.033677	0.116492779	-0.123636075
Corridor 3	85.325	27.50295	665.6761	0.5281	-0.5599
SD	10.21572	1.871836	11.76537	0.121098003	0.123889127
COV	0.119727	0.068059	0.017674	0.229308849	-0.221270096
Corridor 4	55.08	29.127	445.9236	0.7504	-0.7155
SD	3.667818	1.112965	27.12122	0.0865797	0.103269066
COV	0.066591	0.038211	0.06082	0.115378065	-0.144331329

From Table 5.2, it appears that the average speeds of driving cycles in corridors 1, 2 and 3 were found to be 24.1 km/h, 23.8 km/h and 27.5 km/h (15.1, 14.9 and 17.2 mph respectively), while the average trip lengths were 3.92 km, 6.43 km and 6.65 km respectively. The average speed on corridor 4 (the control corridor) is 29.12 km/h (18.2 mph) km/hr. The average corridor trip length of corridor 4 is 445.92 meters. It is clear that the average speed is highest on the control corridor (i.e. the corridor with no speed controlling measures) while the lowest speed was observed on corridor 1 (the corridor with speed cushions, speed humps and cobbled street surface). This is an indication of the effectiveness of speed reduction measures in achieving reduction of speeds in urban areas.

The average journey time for the corridor 1, corridor 2, and corridor 3 were 58.59, 97.73 and 85.32 seconds respectively, whereas the average cycle length for corridor 4 is 55.08 seconds. The average journey on corridor 1 provided data in acceleration and deceleration were found to be 0.55515 m/sec2 and -0.5283 m/sec^2 respectively, whereas the average journey spent on corridor 2 in acceleration and deceleration were found to be 0.72055 m/sec^2 and -0.73475 m/sec^2 respectively. The average journey on corridor 3 in each of the driving modes (acceleration and deceleration) was found to be 0.5281 m/sec^2 and -0.5599 m/sec^2 respectively. For corridor 4, the average journey on acceleration and deceleration were found to be 0.7504 m/sec^2 and -0.7155 m/sec^2 respectively. Further analyses of these statistics are discussed in the following sections.

5.3.1 Journey travel time

Figure 5.6 shows the total travel time during the period of data collection on different corridors. The figure shows that the travel time is significantly high for corridors 1, 2 and 3 as compared to the fourth corridor. This might be a result of the fact that the lengths of the 2nd and 3rd corridors were higher in comparisons with corridor 4 while the length of the first corridor is less than that of corridor 4. The overall speed on the three corridors (1, 2 & 3) where much lower than they are on the fourth corridor (the control) as a result of the speed reduction measures implemented there. Obviously, the reduction of speed on these corridors is the main objective of implementing speed reduction measures, however, as well as reducing speed there is an increase in acceleration and deceleration on these corridors which is not very desirable. This is because speed reduction measures force drivers to reduce their speeds just before speed calming measures and then accelerate again straight after; this results in increase in emissions and subsequently worsening environmental conditions. This will be discussed in the subsequent sections.

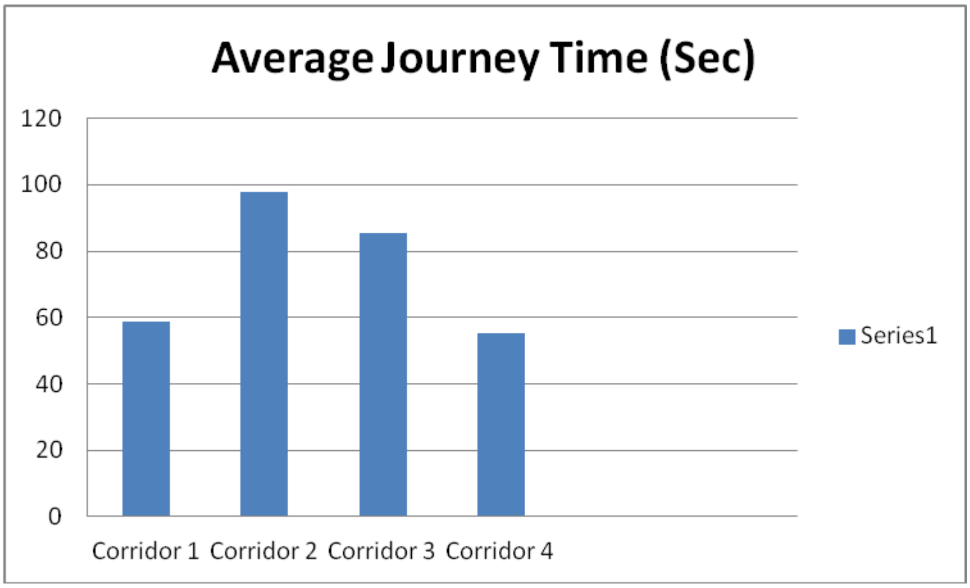


Figure 5.6: The total travel time during the period of data collection on different corridors

5.3.2 Journey speed

Figure 5.7 shows the speeds during the period of data collection on different corridors. The figure shows that the speed of corridor 1, 2 and 3 are lower than all the remaining corridors. This shows that while speed humps only (corridor 2) serves the purpose of reducing speeds, they are more efficient when they are combined with other measures (such as raised junctions or speed cushions).

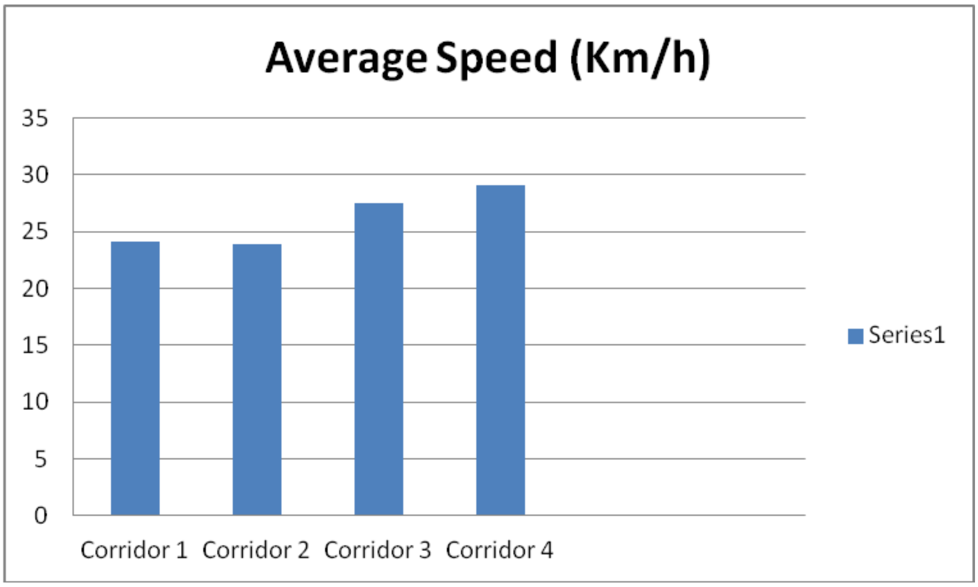


Figure 5.7: The speeds during the period of data collection on different corridors

5.3.3 Journey length

Figure 5.8 shows the length during the period of data collection on different corridors. This can be used to compare the sections under study for data collection. The length of the corridors 2 and 3 was higher than the rest of the corridors as the data collected for these sections used longer length of these corridors. However this does not create any problem with the overall results and they were considered adequate for further analysis.

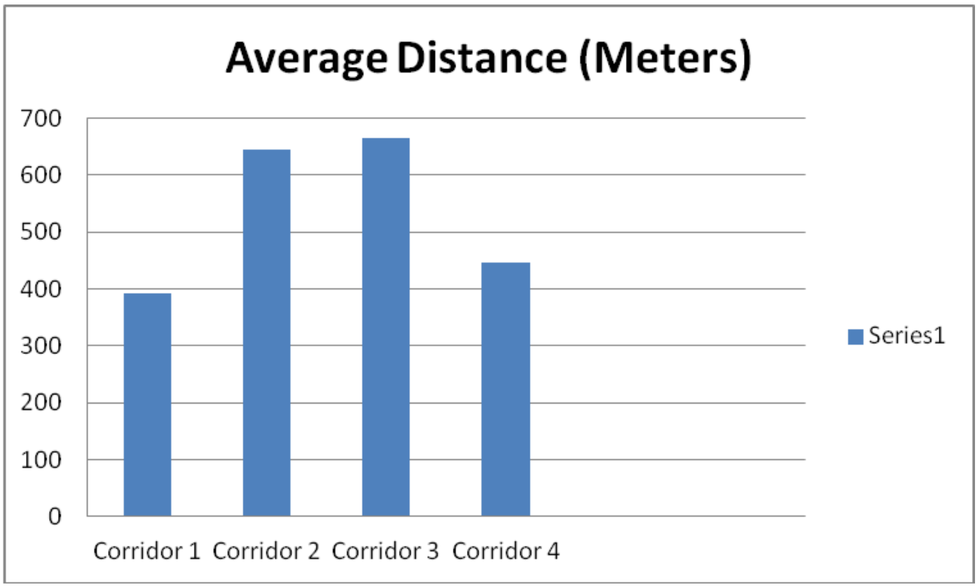


Figure 5.8: The length during the period of data collection on different corridor

5.3.4 Average journey acceleration

Figure 5.9 shows the total average journey acceleration during the period of data collection on the four corridors. The figure shows that the time spent in acceleration is different for the different corridors. The average journey acceleration time for corridor 4 is highest among all the corridors with the average journey time in acceleration on corridor 3 is the lowest. The reason for this can be the effect of different traffic calming measures on these corridors. For example corridor1 with cobbled surface might require constant acceleration whereas raised junctions on corridor 3 in addition to humps keep the vehicles at lower speeds even after the humps. It depicts that although road humps are effective in reducing speed they cause constant acceleration and deceleration of the vehicles whereas other additional measures i.e. raised junctions, keep the vehicles at lower speeds.

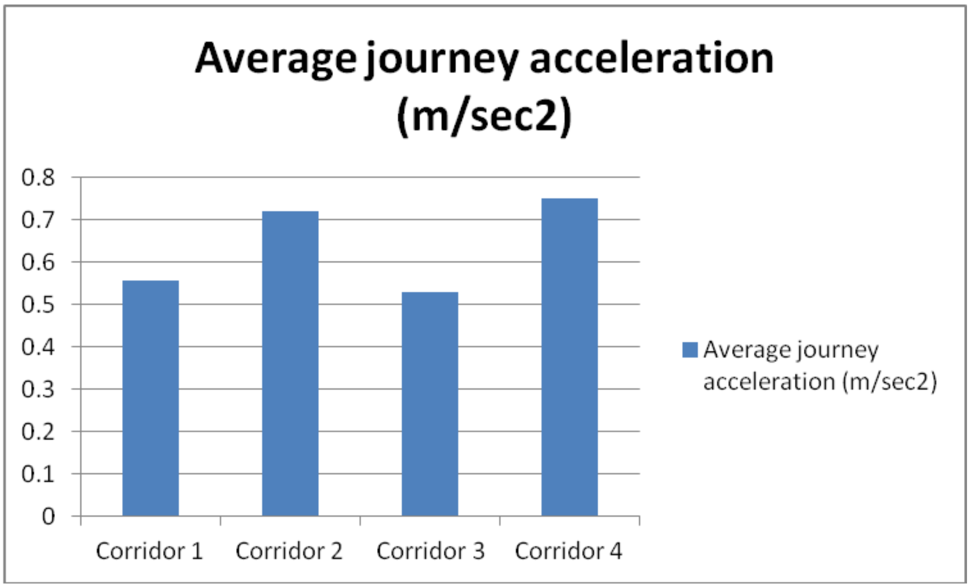


Figure 5.9: The total average journey on acceleration during the period of data collection on the fourth corridor

5.3.5 Average journey deceleration

Figure 5.10 shows the total average journey on deceleration during the period of data collection on different corridors. The figure shows that the average journey deceleration on corridors 1 & 3 are almost similar (higher than 17.3%) and is the highest compared with corridors 2 & 4 with corridor 4 (the control) showing the least % time spent on deceleration.

As mentioned earlier each of corridor 1 and corridor 3 has more than one type of traffic calming measures, corridor 3 has only road humps.

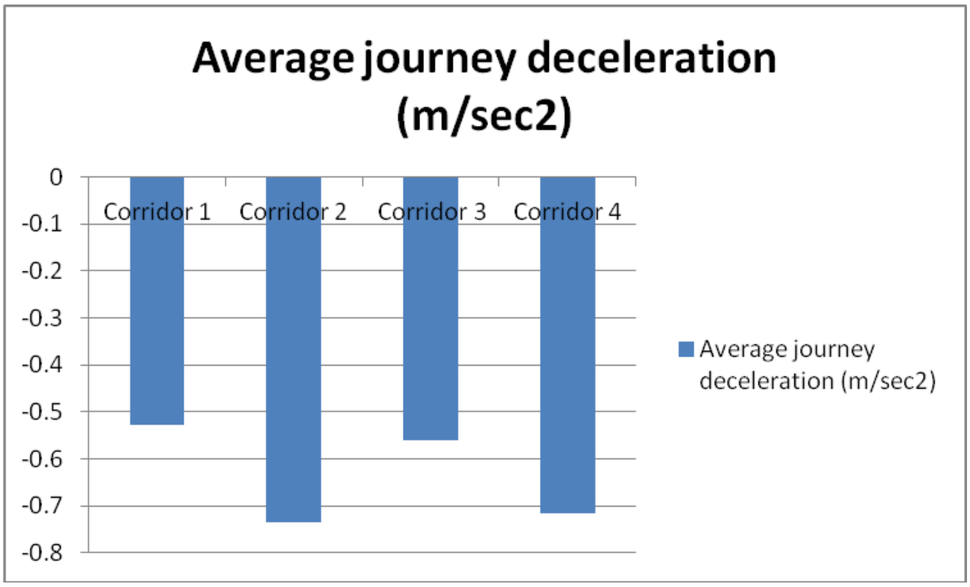


Figure 5.10: The total average journey on deceleration during the period of data collection for each of the mode on different corridors

5.4 Results and preliminary analysis of mixed traffic corridors measures in Abu Dhabi

As mentioned earlier, a novel feature of this study is also the development of Abu Dhabi driving cycle for both buses and cars. Table 5.3 and below present the general characteristics of the mixed traffic corridors in Abu Dhabi. These characteristics are discussed below. These characteristics include the average journey time, average journey speed, average journey acceleration, average journey deceleration, standard deviation and coefficient of variation (COV).

Table 5.3: Characteristics of the mixed traffic corridors in Abu Dhabi

Corridors	Time	Mode	Direction	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	Average Acc (m/sec^2)	Average Dec (m/sec^2)
Airport Road (mixed traffic road)	**6.30.-7.30 am**	**Car**	**Inbound**	252.64	35.628	2387.998	0.83	-0.94
			SD	64.348	7.342	109.843	0.082	0.128
			COV	0.254	0.206	0.045	0.099	-0.136
			Outbound	171.96	44.832	2089.216	0.702	-0.968
			SD	59.256	5.301	642.876	0.143	0.604
			COV	0.344	0.118	0.307	0.204	-0.623
		Bus	**Inbound**	544.9	15.61	2331.912	0.826	-0.876
			SD	81.33	1.878	201.623	0.11	0.118
			COV	0.149	0.12	0.086	0.133	-0.135
			Outbound	422.8	19.907	2302.241	0.838	-1.273
			SD	56.667	2.918	130.622	0.086	0.692
			COV	0.134	0.146	0.056	0.103	-0.543
	11.00-12.00 pm	**Car**	**Inbound**	188.35	45.609	2364.854	0.683	-0.886
			SD	22.335	4.195	114.222	0.194	0.17
			COV	0.118	0.091	0.048	0.285	-0.192
			Outbound	167.9	33.2841	1573.809	0.8215	-1.178
			SD	77.082	7.342	860.927	0.065	0.714
			COV	0.459	0.22	0.547	0.08	-0.606
		Bus	**Inbound**	437.42	19.127	2248.493	0.841	-1.258
			SD	82.297	3.801	103.693	0.085	0.476
			COV	0.188	0.198	0.046	0.101	-0.378
			Outbound	332.17	25.765	2359.612	0.81	-1.568
			SD	32.689	2.31	69.428	0.061	1.087
			COV	0.098	0.089	0.029	0.076	-0.693
Eliktra Road (mixed traffic road)	**6.30.-7.30 am**	**Car**	**Inbound**	209.69	30.552	1762.837	0.935	-3.38
			SD	25.257	3.189	101.124	0.114	4.376
			COV	0.12	0.104	0.057	0.122	-1.294
			Outbound	176.4	35.553	1718.947	0.946	-3.233
			SD	23.879	4.397	97.709	0.143	3.165
			COV	0.135	0.123	0.056	0.152	-0.979
		Bus	**Inbound**	320.29	20.697	1821.542	0.85	-1.081
			SD	37.225	2.247	42.007	0.141	0.402
			COV	0.116	0.108	0.023	0.166	-0.372
			Outbound	408.17	16.315	1840.657	0.917	-1.304
			SD	43.376	1.126	107.873	0.101	0.396
			COV	0.106	0.069	0.058	0.111	-0.303
	11.00-12.00 pm	**Car**	**Inbound**	203.033	33.459	1789.443	0.899	-1.441
			SD	40.822	9.995	84.502	0.055	1.265
			COV	0.201	0.298	0.047	0.062	-0.877
			Outbound	207.777	27.737	1572.042	1.004	-3.529
			SD	35.561	4.123	141.031	0.161	3.787
			COV	0.171	0.148	0.089	0.16	-1.073
		Bus	**Inbound**	291.47	20.636	1649.049	0.867	-1.057
			SD	35.144	3.164	151.085	0.133	0.325
			COV	0.12	0.153	0.091	0.154	-0.307
			Outbound	342.71	15.376	1444.897	1.075	-2.318
			SD	66.402	1.79	212.433	0.258	1.543
			COV	0.193	0.116	0.147	0.24	-0.665

5.4.1 Journey travel time

The average journey times for the mixed-traffic corridors have been calculated and analysed. Firstly, for the mixed-traffic corridor (Airport Road), the average journey times during peak hours for buses were 544.9 sec (inbound) and 422.8 sec (outbound), and for cars were 252.64

sec (inbound) and 171.96 sec (outbound). During off-peak hours, average journey time for buses was 437.42 sec (inbound) and 332.17 sec (outbound), and for cars was 188.35 sec (inbound) and 167.9 sec (outbound).

For the mixed-traffic corridor (Elektra Road), the average journey time during peak hours for buses was 320.29 sec (inbound) and 408.17 sec (outbound), and for cars was 209.69 sec (inbound) and 176.4 sec (outbound). During off-peak hours, average journey time for buses was 291.47 sec (inbound) and 342.71 sec (outbound), and for cars was 203.033 sec (inbound) and 207.777 sec (outbound).

Figure 5.11 shows the total travel time during the period of data collection for each of the modes on different corridors. The figure shows that the travel time is significantly high for buses on both the roads during all times. It depicts that the buses have considerably higher travel time and are not very attractive mode of transport especially in peak hours. It can be expected that with the provision of dedicated bus lanes, the situation would improve and the travel time of buses would decrease as compared to other modes and thus making public transport more attractive. The results show that the buses have travel times on average more than almost 2.5 times higher than the travel times of cars. Bus lanes use a dedicated portion of road area and would be expected to provide considerable improvements in terms of travel time for their appraisal.

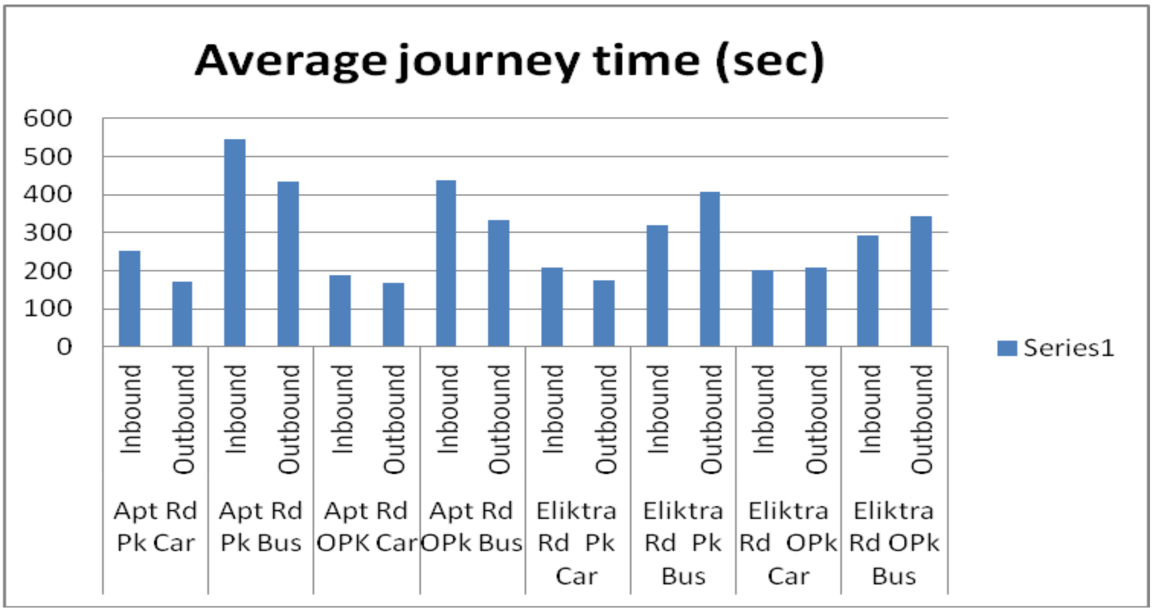


Figure 5.11: The total average travel time during the period of data collection for each of the mode on different corridors

However, there should be careful consideration about the geometry and traffic structure in addition to volumes before provision of any such TDM measure.

5.4.2 Journey speed

The average journey speeds for the mixed-traffic corridors have also been calculated and analysed. Firstly, for the mixed-traffic corridor (Airport Road), the average journey speeds during peak hours for buses were 15.61 km/hr (inbound) and 19.907 km/hr (outbound), and for cars were 35.628 km/hr (inbound) and 44.832 km/hr (outbound). During off-peak hours, average journey speed for buses was 19.127 km/hr (inbound) and 25.765 km/hr (outbound), and for cars was 45.609 km/hr (inbound) and 33.284 km/hr (outbound).

For the mixed-traffic corridor (Elektra Road), the average journey speed during peak hours for buses was 20.502 km/hr (inbound) and 16.873 km/hr (outbound), and for cars was 30.552 km/hr (inbound) and 35.553 km/hr (outbound). During off-peak hours, average journey speed for buses was 20.636 km/hr (inbound) and 15.376 km/hr (outbound), and for cars was km/hr 33.459 (inbound) and km/hr 27.737 (outbound).

Figure 5.12 shows the speeds of cars and buses during the period of data collection on different corridors. The figure shows that the speed of buses is significantly lower than cars on all roads during all times. The speed of buses improves in the non-rush hours but that too is not much improved. On the other hand in rush hours the speeds are less than half of the speeds of cars which make the buses very unattractive during peak hours.

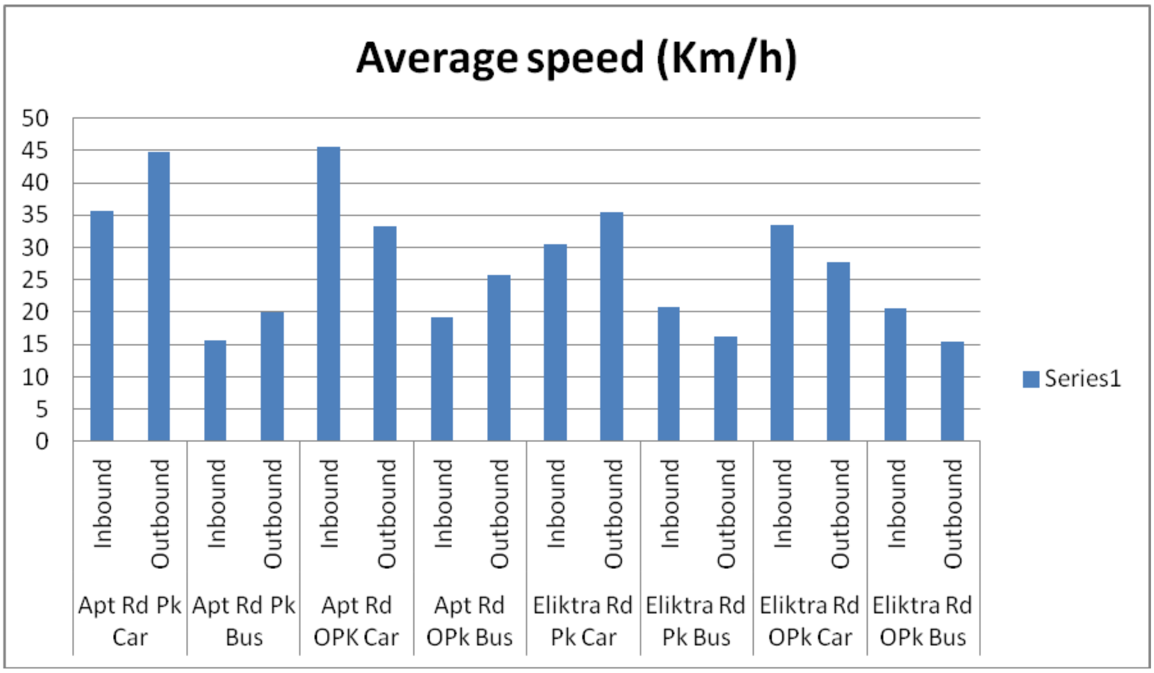


Figure 5.12: The average speeds of cars and buses during the period of data collection on different corridors

5.4.3 Journey length

The average journey length for the mixed-traffic corridor (Airport Road), during peak hours for buses were 2331.912 meters (inbound) and 2302.241 meters (outbound), and for cars were 2387.998 meters (inbound) and 2089.216 meters (outbound). During off-peak hours, average journey length for buses was 2248.493 meters (inbound) and 2359.612 meters (outbound), and for cars was 2364.854 meters (inbound) and 1573.809 meters (outbound).

For the mixed-traffic corridor (Elektra Road), the average journey length during peak hours for buses was 1821.542 meters (inbound) and 1840.797 meters (outbound), and for cars was 1762.837 meters (inbound) and 1718.947 meters (outbound). During off-peak hours, average journey length for buses was 1649.049 meters (inbound) and 1444.897 meters (outbound), and for cars was 1789.443 meters (inbound) and 1572.042 meters (outbound).

Figure 5.13 shows the length during the period of data collection on different corridors. This can be used to compare the sections under study for data collection. The lengths of the routes are comparable and are found to be satisfactory for further analysis.

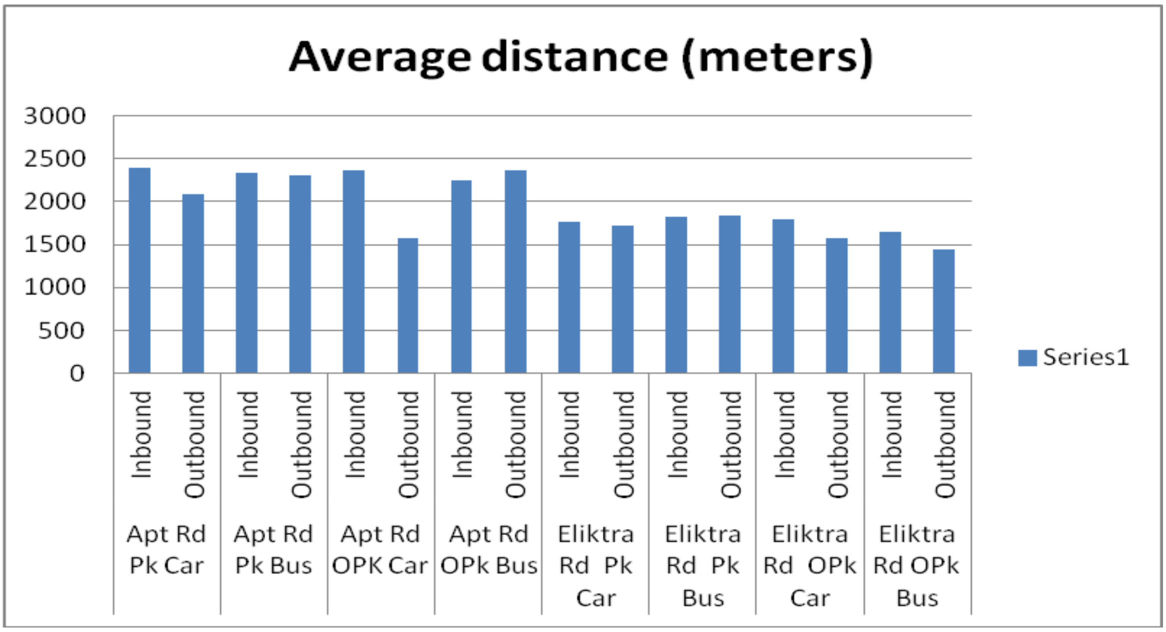


Figure 5.13: The average length during the period of data collection on different corridors

5.4.4 Average journey acceleration

The average journey acceleration on the mixed-traffic corridor (Airport Road), during peak hours for buses was 0.826 m/sec2 (inbound) and 0.838 m/sec^2 (outbound), and for cars was 0.83 m/sec^2 (inbound) and 0.702 m/sec^2 (outbound). During off-peak hours, the average journey acceleration for buses was 0.841 m/sec^2 (inbound) and 0.81 m/sec^2 (outbound), and for cars was 0.683 m/sec^2 (inbound) and 0.821 m/sec^2 (outbound).

Whereas the average journey acceleration on the mixed-traffic corridor (Elektra Road), during peak hours for buses was 0.85 m/sec^2 (inbound) and 0.917 m/sec^2 (outbound), and for cars was 0.935 m/sec^2 (inbound) and 0.946 m/sec^2 (outbound). During off-peak hours, the average journey acceleration for buses was 0.867 m/sec^2 (inbound) and 1.075 m/sec^2 (outbound), and for cars was 0.899 m/sec^2 (inbound) and 1.004 m/sec^2 (outbound).

Figure 5.14 shows the average journey acceleration during the period of data collection for each of the modes on different corridors. The figure shows that the average journey acceleration for buses is almost same as compared to cars during all times.

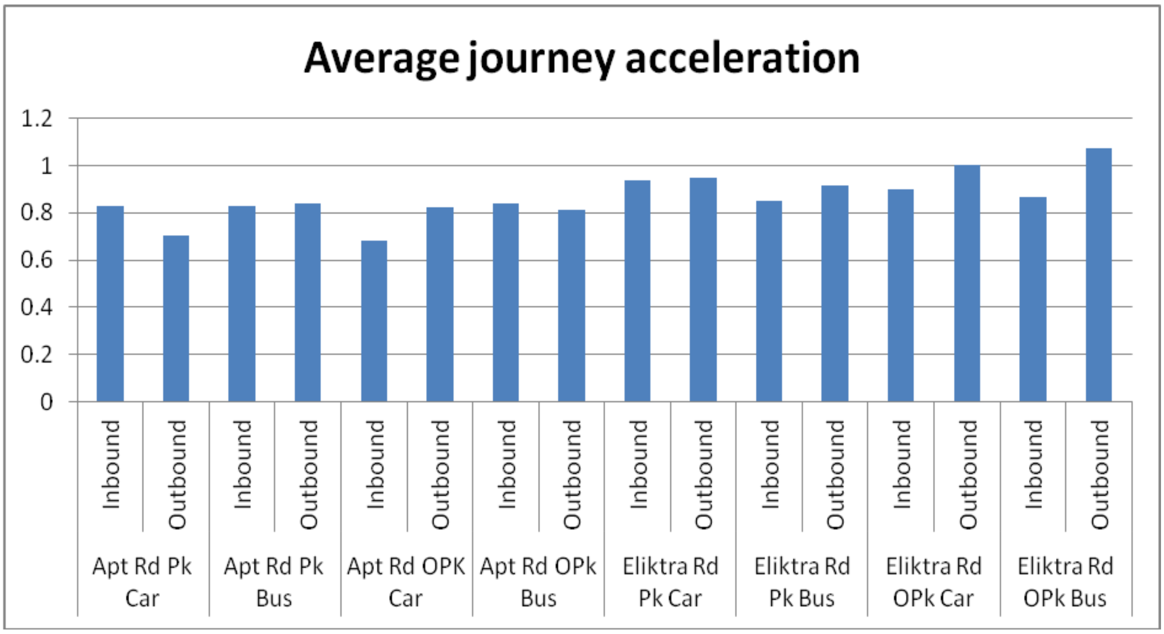


Figure 5.14: The total average acceleration during the period of data collection for each of the mode on different corridors

5.4.5 Average journey deceleration

The average journey deceleration on the mixed-traffic corridor (Airport Road), during peak hours for buses was -0.876 m/sec^2 (inbound) and -1.273 m/sec^2 (outbound), and for cars was -0.94 m/sec^2 (inbound) and -0.968 m/sec^2 (outbound). During off-peak hours, the average journey deceleration for buses was -1.258 m/sec^2 (inbound) and -1.568 m/sec2 (outbound), and for cars was -0.886 m/sec^2 (inbound) and -1.178 m/sec^2 (outbound).

Whereas the average journey deceleration on the mixed-traffic corridor (Elektra Road), during peak hours for buses was -1.081 m/sec^2 (inbound) and -1.304 m/sec^2 (outbound), and for cars was -3.38 m/sec^2 (inbound) and -3.233 m/sec^2 (outbound). During off-peak hours, the average journey deceleration for buses was -1.057 m/sec^2 (inbound) and -2.318 m/sec^2 (outbound), and for cars was -1.441 m/sec^2 (inbound) and -3.529 m/sec^2 (outbound).

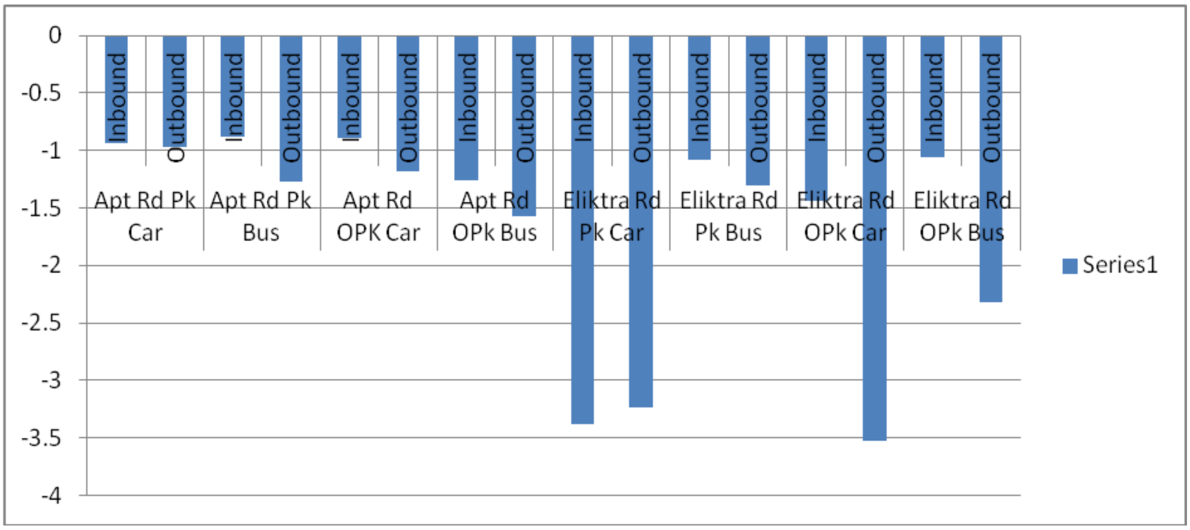


Figure 5.15: The total average deceleration during the period of data collection for each of the mode on different corridors

Figure 5.15 shows the mixed results for the average journey deceleration for buses and cars during all times. On Airport Road the cars in general have higher deceleration phases whereas at Elektra road the buses have higher deceleration phases.

5.5 Summary

This chapter presented the preliminary analysis from the assessment of the bus traffic corridors in Edinburgh and the traffic calming corridors in Edinburgh and Abu Dhabi. This data is used for the development of the driving cycle in both cities. Data was collected for the buses and cars on the “bus traffic corridors” in Edinburgh, “traffic calming corridors” in Edinburgh as well as for buses and cars on the “traffic corridors” in Abu Dhabi. The results of the characteristics of the buses and cars on the bus traffic corridors in Edinburgh have been presented and briefly discussed. The measurements were carried out for each of the three corridors during peak (8.00-9.00 am**)** and off-peak (2.00-3.00 pm**)** hours of traffic as well as before the bus lane operation (6.30-7.30am**)**. The measurements were repeated for both directions of traffic flow on each corridor as well (that is inbound and outbound). The general characteristics of the bus traffic corridors in Edinburgh and Abu Dhabi have been presented. These characteristics are further discussed in the following chapters. These characteristics include the average journey time, average journey speed, average journey acceleration, average journey deceleration, standard deviation and coefficient of variation (COV). Further analysis of the results and the driving cycles are presented in the following chapters.

CHAPTER 6

DEVELOPMENT OF THE DRIVING CYCLES

6.1 Introduction

Development of representative driving cycles is a very important tool for an efficient assessment of transport policies. Therefore, much research has been undertaken on this subject, as discussed in the literature review (e.g. Saleh, et al., 2010; Simanaitis, 1977; Kent et al., 1978; Kulher and Karsten, 1978; Watson et al., 1982; Wang et al., 1985; Lyon et al., 1986; Andre et al., 1995; Tong et al., 1999; Tzeng & Chen et al., 1998; Booth et al., 2001; Shafiepour and Kamalan, 2005; Tsai et al., 2005; Hung et al., 2007).

However, most of the work on the development of driving cycles has been carried out with emission monitoring and measurement, in mind rather than their applications in the area of assessing further travel demand management. Therefore, this is one of the novel areas of this research. While most of this work is immediately relevant to sustainability, one can recognise three main gaps in such work. These are: Firstly, in most studies, emission monitoring and measurement are mostly undertaken separately and as a follow up to the investigation of the problem of congestion. Secondly, the driving cycle techniques and principle are very useful tools. They are applicable for any study area type and the techniques are very flexible. Thirdly, most of the work on driving cycles to date has been reported in the western countries, but not in the developing countries. This is despite that most of developing countries suffer from congestion, pollution and all the other traffic related problems.

In this research, we utilise the techniques of investigating the driving cycle analysis to monitor impacts of traffic management policies. Specifically, two policies have been considered in this research: bus lanes corridors where the performance of buses and cars over these corridors has been investigated. Secondly, traffic calming measures, where a number of corridors with traffic calming measures have been studied and analysed. In addition, traffic corridors in Abu Dhabi have also been investigated.

This Chapter details the methodological development of the driving cycle for the buses and for the cars on the bus lane traffic corridors, as well as for the traffic calming corridors, in Edinburgh's case studies. The assessment of the driving cycle for Abu Dhabi traffic corridors is also presented. Chapters 3 and 4 present the description of the case studies and the methodology for data collection.

6.2 Parameters used for the development of the driving cycle

As discussed earlier in Chapter Four, modelling the driving cycles requires synthesising a large amount of data collected from the field. In each case study, there were large numbers of test runs. Each test run was comprised of a series of major kinematic sequences (i.e. speed vs. time curve) which were divided into a number of minor kinematics sequences (also called micro-trips). This data (which was collected every 0.1 seconds time intervals), was exported to Excel software to calculate the assessment parameters.

The data analysis was carried out using the performance box analysis programme and Microsoft excel. The data collected was edited to remove any errors data such as the time spent stationary while waiting for a car to enter the test area that could be chased. After the data was edited the remaining data was exported to excel and saved as an excel file. Each of the parameters was calculated as below:

Data on speed, time, distance, acceleration, deceleration, idling and cruising were analysed for each of the corridors. A number of assessment parameters were estimated which include:

1. Average trip duration (t);
2. Average speed of the entire driving cycle (v);
3. Mean length of driving period (l);
4. Average acceleration of all acceleration phases (a);
5. Average deceleration of all deceleration phases (d);
6. Percentage time spent in driving modes for acceleration (P_a);
7. Percentage time spent in driving modes for deceleration (P_d);
8. Percentage time spent in driving modes for deceleration (P_d);
9. Percentage time spent in driving modes for cruising (P_c);

10. Standard deviation (S_d);
11. Coefficient of variation (*Cov*);
12. Sum of absolute relative error (*Sj*).

These parameters are defined hereinafter.

1. **Average trip duration (*t*):**

The trip duration was simply obtained by noting the time in seconds of each run.

2. Average speed of the entire driving cycle (*v*);

The average speed was obtained using excels average formulae, which was done by simply highlighting the complete speed data and clicking the average formulae button.

3. Mean length of driving period (*l*);

The average length was obtained using excels average formulae, which was done by simply highlighting the complete length data and clicking the average formulae button.

4. Average acceleration of all acceleration phases (*a*);

To obtain the average acceleration, the column of data that contained the acceleration and deceleration first had to be multiplied by 9.81 to convert the data from gravitate to m/s^2 and then sorted into the range of largest to smallest. After this had been completed all the acceleration section was highlighted and the average found by excels average formulae.

5. Average deceleration of all deceleration phases (*d*);

To obtain the average deceleration, the column of data that contained the acceleration and deceleration first had to be multiplied by 9.81 to convert the data from gravitate to m/s^2 and then sorted into the range of largest to smallest. After this had been completed all the deceleration section was highlighted and the average found by the excel average formulae.

6. Percentage time spent in driving modes for acceleration (P_a);

The percentage of acceleration was obtained using the same converted and sorted excel page. This was done by noting the cell number of the acceleration phase that was immediately greater than the average acceleration and finding the proportion this figure was of the whole data by hand calculations, for example if the data was 1000 cells large and the acceleration that was immediately greater than the average acceleration was at cell 350 that would imply the percentage time spent in acceleration was 350/1000*100=35%.

7. Percentage time spent in driving modes for deceleration (P_d);

The percentage of deceleration was obtained using the same converted and sorted excel page. This was done by noting the cell number of the deceleration phase that was immediately less than the average deceleration and finding the proportion this figure was of the whole data by hand calculations, for example if the data was 1000 cells large and the deceleration that was immediately less than the average deceleration was at cell 700 that would imply the percentage deceleration was 1000-700=300= then (300/1000)*100=30%.

8. Percentage time spent in driving modes for cruising (P_c);

This was obtained by cutting all the acceleration data between the average acceleration and average deceleration values and pasting it in a new excel sheet. Then the data would be sorted in order of speed from smallest to largest. Since idle is defined as less than 10 km/h percentage cruise is the proportion of the cut data above 10 km/h. The proportion was worked out manually in the same manner as percentage acceleration and deceleration.

9. Percentage time spent in driving modes for idle:

This was worked out by using the same process as percentage cruise except it was the proportion of data below 10 km/h.

10. Standard deviation (S_d);

This was obtained by selecting all the data for each parameter on each route and using the standard deviation formulae in excel.

11. Coefficient of variation (*Cov*);

This was obtained by dividing the SD value of each parameter by the average value of that parameter.

12. Sum of absolute relative error (*Sj*).

This was calculated by summing up the individual relative error for the corridors.

6.4 Derivation of driving cycle

The driving cycles were derived by examining the statistical resemblance of the nine defined parameters as shown in Table 6.3. These assessment parameters were also used in assessment of deriving driving cycle by several researchers (Tzeng & Chen et al., 1998, Hung et al., 2007, Tsai, 2005, Andre 2004, Kumar et al., 2007). These parameters are the most appropriate parameters to assess and define the driving cycle for the case of bus lanes assessment and for traffic calming measures assessment. The percentages of time spent in each of the driving cycles are taken to be a good reflection of the efficiency of the policies implemented in terms of impacts on environmental emissions and hence sustainability.

The overall mean value of each of the nine defined parameters, standard deviations (SD) and coefficients of variations (COV) of those assessment parameters were estimated for each of the test runs for each of the corridors. The COV values were calculated to show the variations in the performance of the test runs for the corridors.

A further refining of the driving cycle was done by calculating the absolute sums of the relative error (Sj) then by selecting the driving cycle with minimum value of Sj. The relative error value for each of the parameters (Δ_k) is calculated (see previous discussions in Section 4.10.2):

$$\Delta_k = \frac{(\bar{p} - p_{ij})}{p_{ij}} * 100 \qquad \text{Equation 5.1}$$

Where k is an assessment parameter (k varies from 1 to 9) and Δ_k is the value of the relative error for parameter k, $\bar{p}$ is overall mean value of parameters. P_{ij} is a parameter with a value of a run i (between 1 and number of runs) and corridor category j. The absolute sum of the relative errors (Sj) was calculated for each corridor category type by summing up the individual relative error for a given corridor (Eq. 5.2):

$$S_j = \sum_{k=1}^{7} \Delta k \qquad \text{equation 5.2}$$

These assessment parameters are set for each of the corridors, the details of these routes and time of data collection is presented in Section 3.4:

Table 6.1: Assessment parameters used in deriving the driving cycles for the selected corridors

Assessment parameter	**Abbreviation**
Average trip duration	T
Mean length of driving period	L
Average speed of the entire driving cycle	V
Average acceleration	A
Average deceleration	D
Percentage time spent in driving modes for acceleration	P_a
Percentage time spent in driving modes for deceleration	P_d
Percentage time spent in driving modes for cruising	P_c
Percentage time spent in driving modes for idling	P_i
Standard deviation	Sd
Coefficient of variation	Cov
Sum of absolute relative error	Sj

The minimum value of the sum of absolute error (%) Sj for the corridors in each category was then identified and the corridor driving cycle was selected as a representative driving cycle for that category. For example, for the bus corridors in Edinburgh, the inbound and outbound traffic corridors where analysed and compared and the driving cycle with the minimum (%) Sj was selected to be the representative driving cycle for the bus lane corridors.

6.5 Selected traffic corridors for the study

As discussed earlier in Section 3.4, a number of traffic corridors have been tested in this research. These include firstly, three traffic corridors in Edinburgh were investigate and assess the performance of traffic which include the buses and the private cars and investigate the impacts of bus lanes. These three corridors are referred to in this study as “Edinburgh bus traffic corridors”. Secondly, there are four “Edinburgh traffic calming corridors”; three with traffic calming measures and one used as a control corridor. The performance of the cars on these corridors has been investigated. Finally, there are two traffic corridors in the city of Abu Dhabi, and these are referred to as “Abu Dhabi traffic corridors”. On these corridors, the performance of the cars and buses are investigated.

Firstly, the Edinburgh bus traffic corridors consist of:

1. A corridor with a bus lane (i.e. a lane is used exclusively by buses from (7.30-9.30 am and from 16.00-18.30 pm). This type of corridor is referred to in this study as a “bus-lane corridor”. These corridors are represented in this study by corridor A7 (Nicolson Street) in Edinburgh.

2. A corridor with mixed traffic. That is the bus as well as all other traffic share all the lanes of the corridor. These types of corridors are referred to in this study as “mixed traffic corridors”. These corridors are represented in this study by corridor A702 (Morningside Road) in Edinburgh.

3. A corridor which is designated to buses, which is in fact a very special case. However, Princes Street in Edinburgh is designated to bus and taxi operations only and no other traffic can use the road. Therefore, this has been an interesting case which was worthy of investigation and comparisons with other traffic corridors. These types of corridors are referred to in this study as “bus-only corridors”, and represented in this study by Princes Street corridor in Edinburgh.

Secondly, the traffic calming corridors consists of:

4. A corridor with a 20 mph zone speed cushions, speed humps and cobbled street surface. This type of corridor is referred to in this study as a “Traffic calming-corridor-1”. These corridors are represented in this study by corridor 1 (Iona Street) in Edinburgh.
5. A corridor with a 20 mph zone with speed humps. This type of corridor is referred to in this study as a “Traffic calming-corridor-2”. These corridors are represented in this study by corridor 2 (West Bryston Road) in Edinburgh.
6. A corridor with a 20 mph zone with speed humps and raised junctions. This type of corridor is referred to in this study as a “Traffic calming-corridor-3”. These

corridors are represented in this study by corridor 3 (Montgomery Street) in Edinburgh.

7. A corridor with no traffic calming measures. This type of corridor is referred to in this study as a “control corridor”. These corridors are represented in this study by corridor 4 (Polwarth Terrace) in Edinburgh.

Thirdly, the traffic corridors in Abu Dhabi consist of: Two corridors with mixed traffic (i.e. all traffic share all lanes on the corridor). These corridors are represented in this study by Airport Road and Elektra Road in Abu Dhabi.

Table 6.2 below shows the general characteristics of the five traffic corridors selected in this study.

Table 6.2: General characteristics of the selected corridors in this study

The corridors	**Number of bus stops**		**Number of Signalised junctions**		**Number of pedestrians crossing**		**Bus frequency**		**Number of bus routes**		**Type of road**	**Number of lanes**	**Length of the corridor**
Direction	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In**	**Out**	**In/Out**	**In/Out**	**In/Out**
A7 (Bus lane)	7	8	6	6	6	6	57	57	10	10	Single carriageway	2	0.9 miles
A702 (Mixed traffic)	7	5	5	5	5	5	36	36	6	6	Single carriageway	2	1.0 miles
Princes St (Bus only)	9	12	7	7	4	4	156	156	29	29	Dual carriageway	2	0.7 miles
Airport Rd (Mixed traffic)	6	6	4	4	0	0	24	24	4	4	Dual carriageway	4	1.0 miles
Elektra Rd (Mixed traffic)	5	6	4	4	0	0	42	42	7	7	Dual carriageway	3	1.0 miles

6.6 Development of driving cycles for traffic corridors in Edinburgh

As discussed earlier, driving data was collected over three traffic corridors in Edinburgh. Each testing period was comprised of a series of major kinematic sequences (i.e. speed vs. time curve) which were divided into a number of minor kinematics sequences (also called micro-trips) as discussed. Data collected over these three routes were quite huge.

The data was collected via instrumented car installed with performance box driven by the author on the Morningside road A702 which is a mixed traffic road without a dedicated bus lane for both peak and off-peak hours. For bus data, it was collected by carrying the performance box on the bus.

Ten tests were completed for each of the three corridors, for each direction of traffic (inbound and outbound) and for three time periods peak (8.00-9.00), off peak (2.00-3.00) and before 7.30 (6.30-7.30). As discussed earlier, the time period 6.30-7.30 was the time period before the operation of the bus lanes on the traffic corridors in Edinburgh. These were taken to identify any impacts of the bus lane operation. Therefore, there are six sets of measurements (twenty tests in each measurement) for the A7 corridor, and four sets of measurements for the Morningside (A702) and two sets for the Princes Street corridors; that is twelve sets of measurement as presented in the example in Table 6.3. Appendix 1 presents all the results for all the corridors.

Firstly, an investigation of the results was carried out to check any major problems in the data. There were a few tests excluded from the analysis where the accuracy of the signals from the GPS receiver were not very high (3 receivers only or less were reported). The following sections present the results of each set of measurements. Table 6.4 shows the average values of the parameters for all traffic corridors in Edinburgh

Table 6.3: Example of data collected for corridor A702

The Routes	Time (sec)	Speed (km/hr)	Distance (meters)	% time of Acceleration	% time of Deceleration	% time of Idling	% time of Cruising
A702 T(1) 8-9 Am (In) Bus	278.1	14.34	1108.75	0.1308	0.037	0.213	0.617
A702 T(2) 8-9 Am (In) Bus	316.3	14.59	1281.789	0.152	0.03002	0.297	0.519
A702 T(3) 8-9 Am (In) Bus	403.8	14.39	1614.968	0.182	0.195	0.186	0.435
A702 T(4) 8-9 Am (In) Bus	490.9	10.34	1410.305	0.123	0.027	0.296	0.55
A702 T(5) 8-9 Am (In) Bus	398.3	12.78	1414.246	0.105	0.035	0.355	0.503
A702 T(6) 8-9 Am (In) Bus	535.2	9.61	1430.122	0.119	0.072	0.28	0.526
A702 T(7) 8-9 Am (In) Bus	506.6	9.38	1320.265	0.053	0.036	0.281	0.628
A702 T(8) 8-9 Am (In) Bus	317.3	16.407	1446.358	0.203	0.212	0.18	0.403
A702 T(9) 8-9 Am (In) Bus	322.4	17.97	1609.487	0.197	0.143	0.19	0.468
A702 T(10) 8-9 Am (In) Bus	423.5	13.53	1592.152	0.17001	0.102	0.312	0.415
A702 T(1) 8-9 Am (Out) Bus	260.4	18.88	1366.006	0.093	0.031	0.221	0.653

A702 T(2) 8-9 Am (Out) Bus	318	20.12	1777.861	0.205	0.213	0.15	0.43
A702 T(3) 8-9 Am (Out) Bus	498.4	11.71	1621.731	0.104	0.026	0.28	0.588
A702 T(4) 8-9 Am (Out) Bus	441.1	14.47	1773.561	0.103	0.028	0.342	0.524
A702 T(5) 8-9 Am (Out) Bus	228.8	17.18	1092.903	0.109	0.063	0.256	0.57
A702 T(6) 8-9 Am (Out) Bus	344.5	18.39	1760.303	0.207	0.191	0.171	0.429
A702 T(7) 8-9 Am (Out) Bus	374.3	16.34	1699.303	0.165	0.018	0.272	0.544
A702 T(8) 8-9 Am (Out) Bus	293.8	15.23	1243.295	0.101	0.023	0.377	0.497
A702 T(9) 8-9 Am (Out) Bus	402.6	15.88	1776.589	0.202	0.194	0.255	0.347
A702 T(10) 8-9 Am (Out) Bus	348	15.81	1528.255	0.154	0.032	0.328	0.483
Average	375.115	14.867	1493.413	0.1438905	0.085401	0.2621	0.50645
SD	87.491	3.0154	216.4553	0.045921856	0.074837573	0.0654	0.08172
COV	0.2332	0.2028	0.14494	0.31914446	0.876307924	0.2496	0.16136

Table 6.4: The average values of the parameters for all traffic corridors in Edinburgh

The corridors	Values	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 Bus (8.00-9.00 am)	Average	369.96	13.781	1389.987	0.169	0.127	0.302	0.398
	SD	52.395	2.344	126.126	0.047	0.075	0.087	0.069
	COV	0.141	0.1701	0.0907	0.28002	0.595	0.288	0.173
A7 Bus (2.00-3.00 pm)	Average	390.747	13.276	1398.571	0.173	0.127	0.298	0.4002
	SD	59.242	2.496	112.235	0.0308	0.065	0.091	0.074
	COV	0.151	0.188	0.0802	0.177	0.513	0.306	0.186
A7 Bus (6.30-7.30 am)	Average	228.856	18.961	1193.168	0.127	0.077	0.206	0.587
	SD	59.575	3.403	293.274	0.058	0.068	0.091	0.095
	COV	0.2603	0.179	0.245	0.459	0.886	0.444	0.163
A702 Bus (8.00-9.00 am)	Average	375.115	14.867	1493.413	0.143	0.085	0.262	0.506
	SD	87.491	3.015	216.455	0.045	0.074	0.065	0.081
	COV	0.233	0.202	0.144	0.319	0.876	0.249	0.161
A702 Bus (2.00-3.00 pm)	Average	383.336	14.861	1543.853	0.133125	0.071	0.263	0.527
	SD	54.971	2.738	174.884	0.041	0.053	0.058	0.054
	COV	0.143	0.184	0.113	0.3106	0.745	0.2204	0.104
A7 Car (8.00-9.00 am)	Average	241.288	22.377	1463.595	0.192	0.176	0.109	0.519
	SD	41.246	3.593	92.36	0.019	0.047	0.053	0.062
	COV	0.17	0.16	0.063	0.101	0.265	0.483	0.12
A7 Car (2.00-3.00 pm)	Average	289.05	19.017	1488.154	0.184	0.169	0.156	0.488
	SD	47.22	3.259	60.556	0.017	0.045	0.057	0.076
	COV	0.163	0.171	0.04	0.093	0.269	0.369	0.156
A7 Car (6.30-7.30 am)	Average	166.483	32.168	1463.018	0.183	0.176	0.065	0.572
	SD	19.573	5.488	106.211	0.027	0.043	0.048	0.094
	COV	0.117	0.17	0.072	0.151	0.248	0.75	0.165
A702 Car (8.00-9.00 am)	Average	264.31	21.298	1530.51	0.16215	0.105	0.159	0.564
	SD	36.711	3.773	169.415	0.035	0.058	0.053	0.072
	COV	0.138	0.177	0.11	0.216	0.557	0.337	0.127
A702 Car (2.00-3.00 pm)	Average	289.095	20.64	1595.436	0.167	0.125	0.172	0.532
	SD	65.53	3.929	121.955	0.036	0.065	0.08	0.09
	COV	0.226	0.19	0.076	0.218	0.524	0.465	0.1706
Princes St (8.00-9.00 am)	Average	266.789	14.92	1059.044	0.197	0.184	0.239	0.378
	SD	65.226	3.125	158.093	0.013	0.051	0.092	0.085
	COV	0.244	0.209	0.149	0.069	0.276	0.386	0.226
Princes St	Average	229.884	18.0909	1141.268	0.198	0.187	0.146	0.45

(2.00-3.00 pm)	SD	23.273	2.066	94.767	0.0303	0.045	0.047	0.042
	COV	0.101	0.114	0.083	0.152	0.2405	0.327	0.094

6.7 Driving cycles of the selected corridors

This section presents the development of the driving cycle for all the selected corridors in this study which includes “Edinburgh bus traffic corridors”, “Edinburgh traffic calming corridors” and “Abu Dhabi traffic corridors”. Data collection was carried out using a GPS, a performance box and data logging equipment, while travelling on the buses or by driving an equipped car. Data was collected during peak and off peak hours and before 7.30 am (before the operation of the bus lanes), inbound (I) and outbound (O) for each of the car and the bus for the “Edinburgh bus traffic corridors” and on “Abu Dhabi traffic corridors” but only during one time period on the “Edinburgh traffic calming corridors”.

In total, there are 24 sets of measurements investigated for the driving cycle in Edinburgh and Abu Dhabi. Representative driving cycles were selected for each traffic corridor type from each of the inbound and outbound data sets based on the lowest value of Sj as discussed earlier.

Data was analysed and representative driving cycles was identified for each corridor:

6.8 Development of driving cycles for “Edinburgh bus traffic corridors”

As discussed in earlier, data was collected over the A7, A702 and Princes Street in Edinburgh for cars and buses. Measurements were taken on both inbound and outbound directions on each corridor during both peak and off peak periods. Each two data sets (inbound and outbound) were analysed and assessed for each traffic corridor, to identify the representative driving cycles for each corridor. Therefore, there resulted 12 representative driving cycles for the “Edinburgh bus traffic corridors”. These are a driving cycle for each of the car and the bus on each of the “Edinburgh bus traffic corridors” during peak and off peak and before 7.30am (for the bus-lane corridor) as presented in Table 6.5 below. It should also be noted, that the Princes Street corridor has no cars.

Table 6.5: Summary statistics of driving cycle parameters for Edinburgh bus traffic corridors"

Route	Time	Mode	Direction	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% time of Acc	% time of Dec	% time of Idling	% time of Cruising	Sj
A7 (bus lane road)	8.00-9.00 Am	Car	Inbound	250.022	21.353	1446.969	0.197	0.174	0.108	0.517	0.613
			Outbound	232.555	23.401	1480.22	0.187	0.178	0.11	0.52	0.306
		Bus	Inbound	385.72	12.273	1297.961	0.143	0.107	0.344	0.401	0.038
			Outbound	354.2	15.29	1482.013	0.195	0.147	0.259	0.396	-6.528
	2.00-3.00 Pm	Car	Inbound	286.18	18.79	1444.447	0.177	0.16	0.168	0.492	-1.438
			Outbound	291.92	19.245	1531.861	0.191	0.178	0.144	0.483	-2.527
		Bus	Inbound	419.1	11.794	1313.907	0.159	0.12	0.354	0.369	-2.507
			Outbound	365.23	14.759	1474.767	0.188	0.133	0.248	0.427	-4.849
	6.30-7.30 Am	Car	Inbound	163.044	31.946	1436.173	0.188	0.183	0.068	0.557	1.543
			Outbound	169.922	32.39	1489.863	0.178	0.169	0.061	0.588	1.068
		Bus	Inbound	189.085	17.638	931.191	0.082	0.04	0.262	0.612	9.93
			Outbound	259.788	19.989	1396.928	0.161	0.106	0.162	0.567	0.018
A702 (no bus lane road)	8.00-9.00 Am	Car	Inbound	253.68	20.545	1422.66	0.154	0.106	0.153	0.583	3.504
			Outbound	276.122	22.051	1650.357	0.169	0.104	0.165	0.544	0.029
		Bus	Inbound	399.24	13.333	1422.844	0.143	0.088	0.259	0.506	1.003
			Outbound	350.99	16.401	1563.981	0.144	0.081	0.265	0.506	-0.256
	2.00-3.00 Pm	Car	Inbound	259.37	22.046	1568.821	0.178	0.147	0.138	0.533	-0.408
			Outbound	318.82	19.234	1622.052	0.155	0.103	0.207	0.531	-2.689
		Bus	Inbound	405.41	12.964	1451.403	0.118	0.065	0.275	0.539	3.636
			Outbound	358.811	16.758	1646.576	0.148	0.077	0.249	0.515	-0.485
Prince s St (bus only road)	8.00-9.00 Am	Bus	Inbound	286.52	14.426	1091.004	0.196	0.198	0.25	0.352	-2.302
			Outbound	244.866	15.414	1023.532	0.197	0.171	0.226	0.407	0.77
	2.00-3.00 Pm	Bus	Inbound	235.31	16.741	1082.989	0.207	0.194	0.149	0.447	1.103
			Outbound	223.855	19.44	1206.023	0.19	0.18	0.142	0.454	0.422

6.8.1 Characteristics of "bus-lane corridor" driving cycle in Edinburgh

The mean values of the key parameters are presented in Table 6.5 with the derived driving cycles for the representative driving cycles as discussed above. The characteristics of the representative driving cycles for each of the 12 corridor types are discussed briefly below. Further discussions, comparisons and analysis of these statistics are presented in Chapter seven.

6.8.1.1 Car driving cycle during peak-hour (8.00-9.00 am) on bus-lane corridors

The mean values of the key parameters are presented in Table 6.5 with the derived driving cycles for bus lane corridors in Edinburgh as shown in Figure 6.1 below. The average driving time for this corridor is 232.555 seconds, the average speed on the corridor is 23.401 km h^{-1} and the average trip length on the corridor is 1480.22 meters. The percentage time spent on acceleration, deceleration, idling and cruising on the corridor is 18.72%, 17.9%, about 11.1% and 52.1% respectively. Obviously, speed is one of the most important criteria affecting traffic emission. Figure 6.1 below shows the representative driving cycle for cars on bus-lane corridor (peak hour).

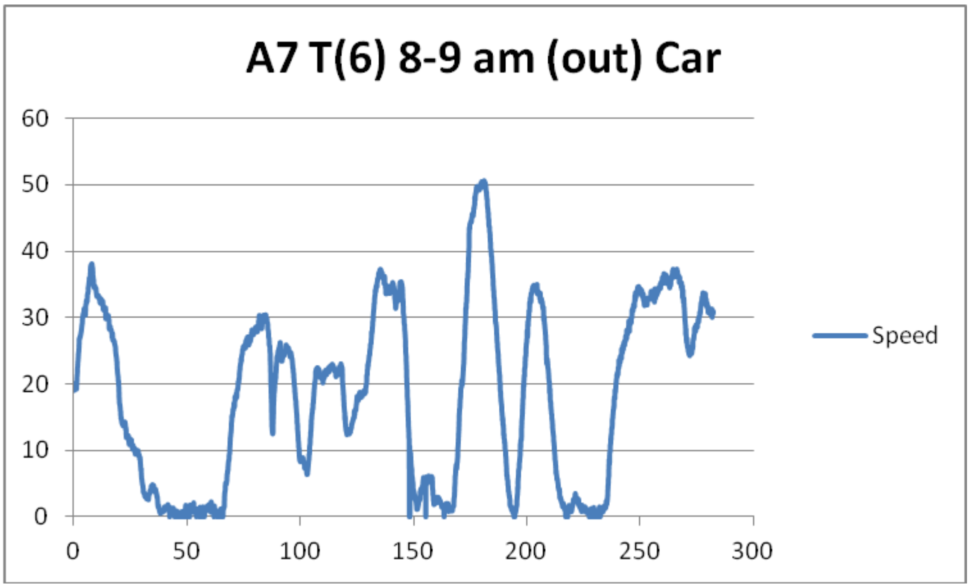


Figure 6.1: The representative Peak-hour driving cycle for cars on bus-lane corridor (peak hour)

6.8.1.2 Car driving cycle during off-peak-hours (2.00-3.00 pm) on bus-lane corridors

The average driving time for this corridor is 291.92 seconds, the average speed on the corridor is 19.245 km h^{-1} and the average trip length on the corridor is 1531.861 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.191 %, 0.178 %, about 0.144 % and 0.483 % respectively. Figure 6.2 below show the representative driving cycle for cars on bus-lane corridor (off peak hour).

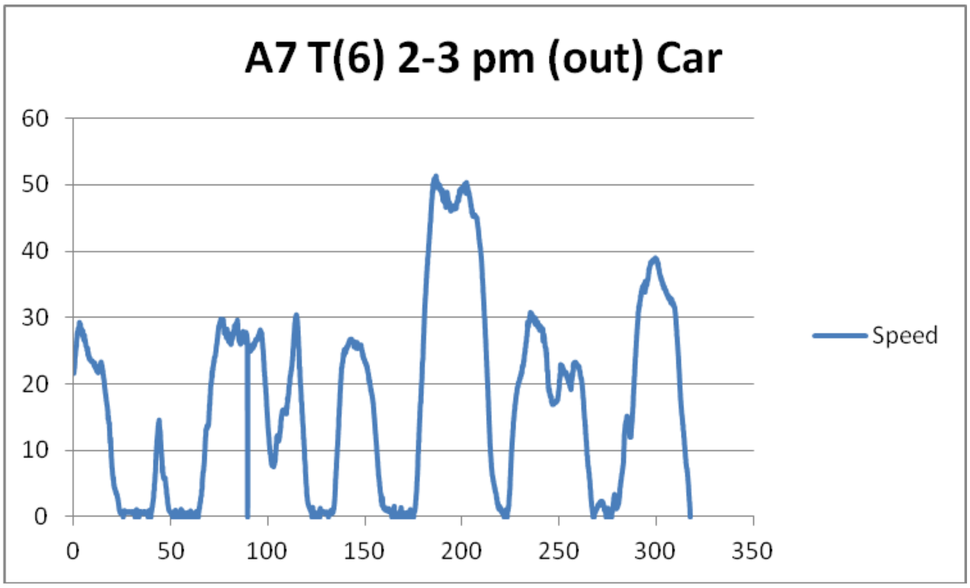


Figure 6.2: The representative Peak-hour driving cycle for cars on bus-lane corridor (before 6.30 am)

6.8.1.3 Car driving cycle during before bus-lane operation (6.30-7.30 am) on bus-lane corridors

The average driving time for this corridor is 169.922 seconds, the average speed on the corridor is 32.39 km h^{-1} and the average trip length on the corridor is 1489.863 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.178 %, 0.169 %, about 0.061 % and 0.588 % respectively. Figure 6.3 below shows the representative driving cycle for cars on bus-lane corridor (before 6.30 am).

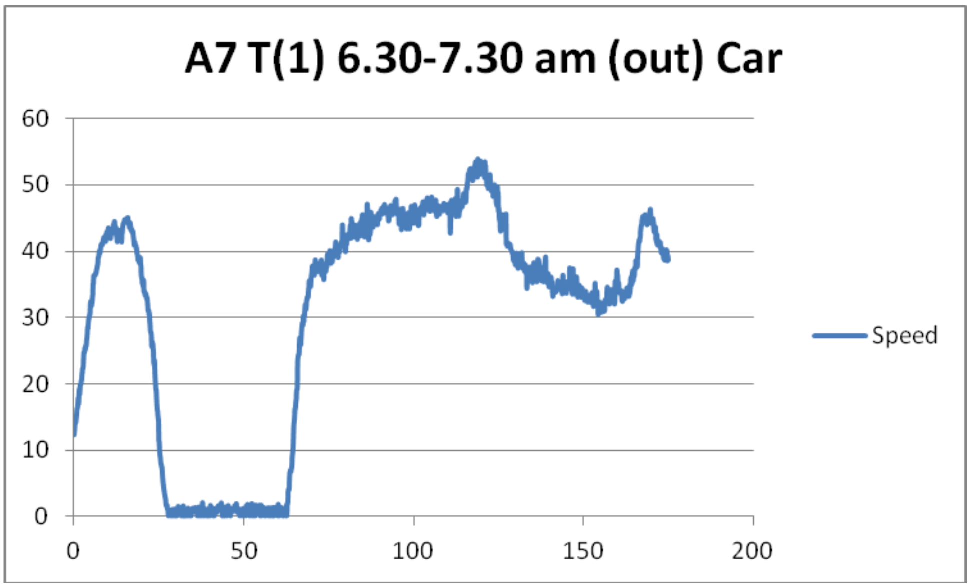


Figure 6.3: The representative Peak-hour driving cycle for cars on bus-lane corridor (before 6.30 am)

6.8.1.4 Bus driving cycle during peak-hour (8.00-9.00 am) on bus-lane corridors

The average driving time for this corridor is 354.2 seconds, the average speed on the corridor is 15.29 km h^{-1} and the average trip length on the corridor is 1482.013 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.195 %, 0.147 %, about 0.259 % and 0.396 % respectively. Figure 6.4 below shows the representative driving cycle for the buses on the bus-lane corridor (peak hour).

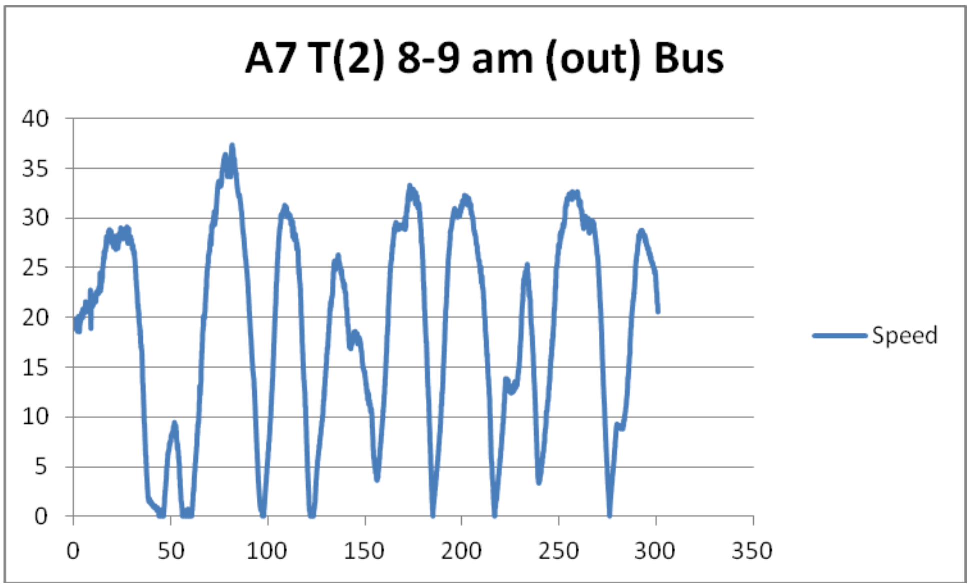


Figure 6.4: The representative driving cycle for buses on bus-lane corridor (peak hour)

6.8.1.5 Bus driving cycle during off-peak-hours (2.00-3.00 pm) on bus-lane corridors

The average driving time for this corridor is 365.23 seconds, the average speed on the corridor is 14.759 km h^{-1} and the average trip length on the corridor is 1474.767 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.188 %, 0.133 %, about 0.248 % and 0.427 % respectively. Figure 6.5 below shows the representative driving cycle for buses on bus-lane corridor (off peak hour).

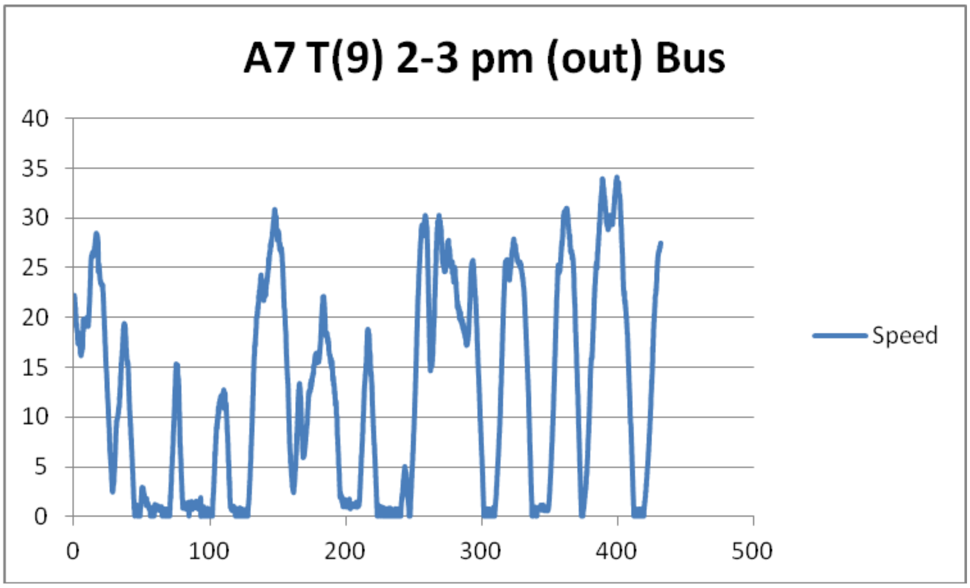


Figure 6.5: The representative driving cycle for buses on bus-lane corridor (off peak hour)

6.8.1.6 Bus driving cycle during before bus-lane operation (6.30-7.30 am) on bus-lane corridors

The average driving time for this corridor is 259.788 seconds, the average speed on the corridor is 19.989 km h^{-1} and the average trip length on the corridor is 1396.928 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.161 %, 0.106 %, about 0.162 % and 0.567 % respectively. Figure 6.6 below shows the representative driving cycle driving cycle for buses on bus-lane corridor (before 6.30 am).

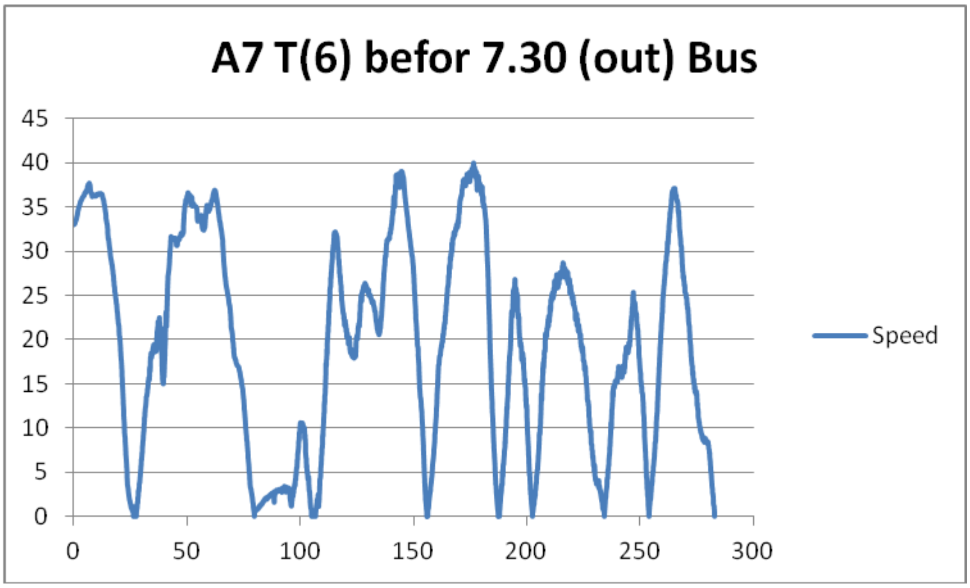


Figure 6.6: The representative driving cycle for buses on bus-lane corridor (before 6.30 am)

6.8.2 Characteristics of the "mixed traffic corridors" driving cycle

The mean values of the key parameters are presented in Table 6.5 with the derived driving cycles for the representative driving cycles as discussed above. The characteristics of the representative driving cycles are discussed briefly below. Further discussions, comparisons and analysis of these statistics are presented in Chapter Seven.

6.8.2.1 Car driving cycle during peak-hour (8.00-9.00 am) on mixed traffic corridors

The average driving time for this corridor is 276.122 seconds, the average speed on the corridor is 22.051 km h^{-1} and the average trip length on the corridor is 1650.357 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.169 %, 0.104 %, about 0.165 % and 0.544 % respectively. Figure 6.7 below shows the representative driving cycle driving cycle for cars on mixed traffic corridor (peak hour).

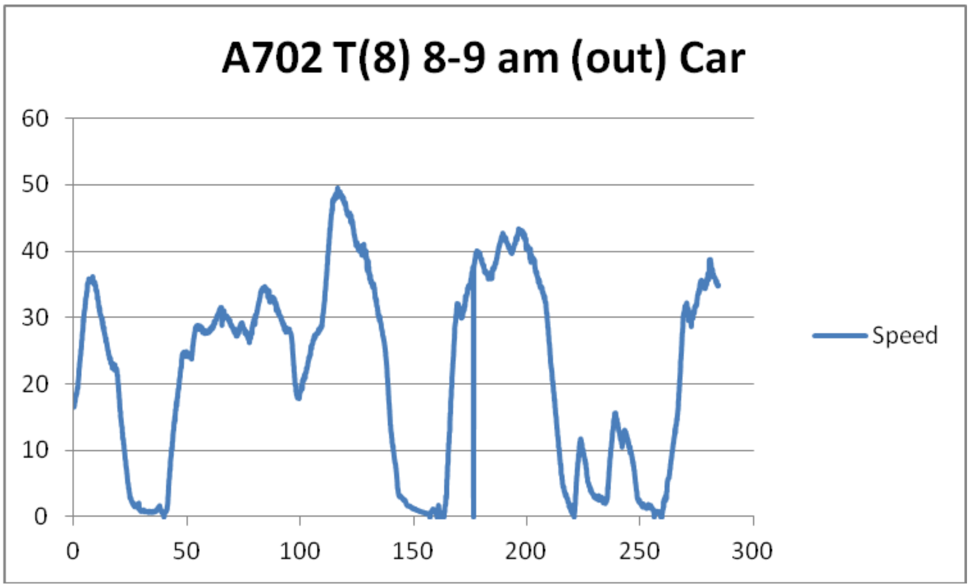


Figure 6.7: The representative driving cycle for cars on mixed traffic corridor (peak hour)

6.8.2.2 Car driving cycle during off-peak-hours (2.00-3.00 pm) on mixed traffic corridors

The average driving time for this corridor is 318.82 seconds, the average speed on the corridor is 19.234 km h^{-1} and the average trip length on the corridor is 1622.052 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.155 %, 0.103 %, about 0.207 % and 0.531 % respectively. Figure 6.8 below shows the representative driving cycle for cars on mixed traffic corridor (off peak hour).

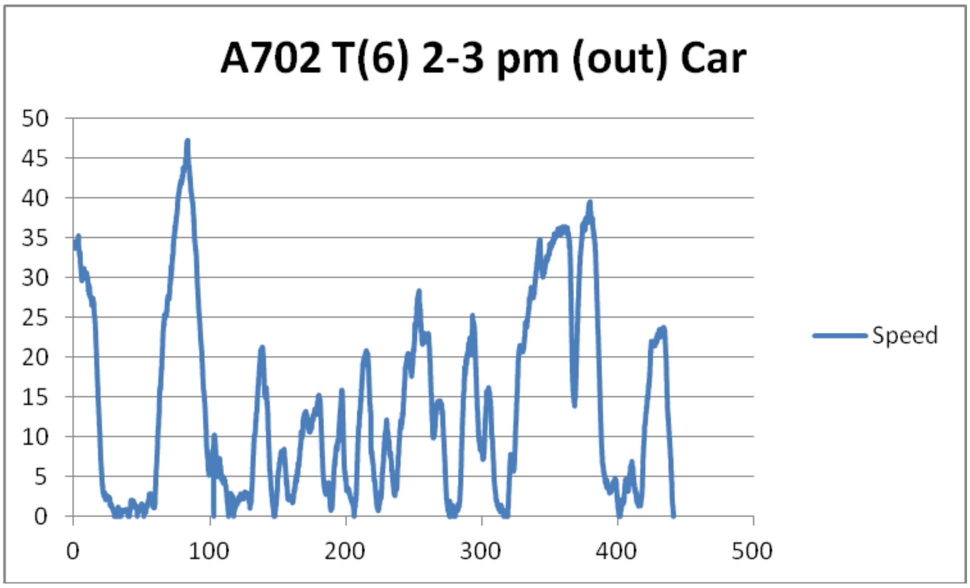


Figure 6.8: The representative driving cycle for cars on mixed traffic corridor (off peak hour)

6.8.2.3 Bus driving cycle during peak-hour (8.00-9.00 am) on mixed traffic corridors

The average driving time for this corridor is 350.99 seconds, the average speed on the corridor is 16.401 km h^{-1} and the average trip length on the corridor is 1563.981 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.144 %, 0.081 %, about 0.265 % and 0.506 % respectively. Figure 6.9 below shows the representative driving cycle for buses on mixed traffic corridor (peak hour).

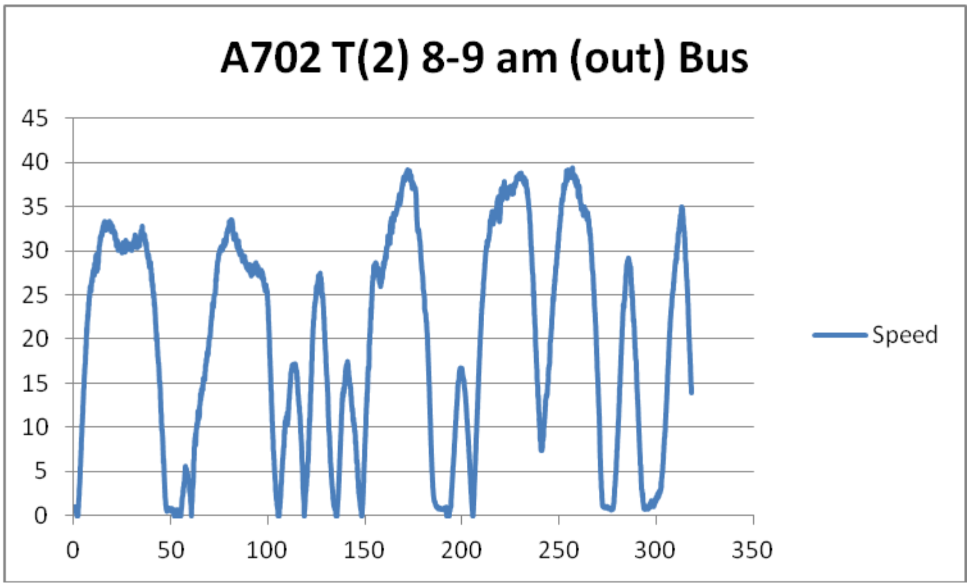


Figure 6.9: The representative driving cycle for buses on mixed traffic corridor (peak hour)

6.8.2.4 Bus driving cycle during off-peak-hours (2.00-3.00 pm) on mixed traffic corridors

The average driving time for this corridor is 358.811 seconds, the average speed on the corridor is 16.758 km h^{-1} and the average trip length on the corridor is 1646.576 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.148 %, 0.077 %, about 0.249 % and 0.515 % respectively. Figure 6.10 below shows the representative driving cycle for buses on mixed traffic corridor (off peak hour).

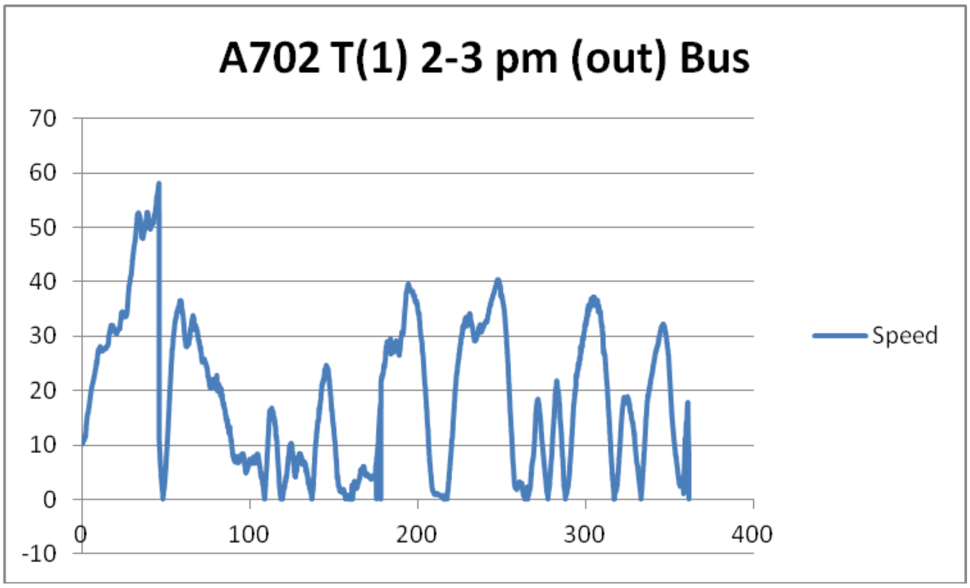


Figure 6.10: The representative driving cycle for buses on mixed traffic corridor (off peak hour)

6.8.3 Characteristics of the bus-only corridor driving cycle

The mean values of the key parameters are presented in Table 6.5 with the derived driving cycles for the representative driving cycles as discussed above. The characteristics of the representative driving cycles are discussed briefly below. Further discussions, comparisons and analysis of these statistics are presented in Chapter Seven.

6.8.3.1 Bus driving cycle during peak-hour (8.00-9.00 am) on bus-only corridors

The average driving time for this corridor is 286.52 seconds, the average speed on the corridor is 14.426 km h^{-1} and the average trip length on the corridor is 1091.004 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.196 %, 0.198 %, about 0.25 % and 0.352 % respectively. Figure 6.11 below shows the representative driving cycle for buses on bus only corridor (peak hour).

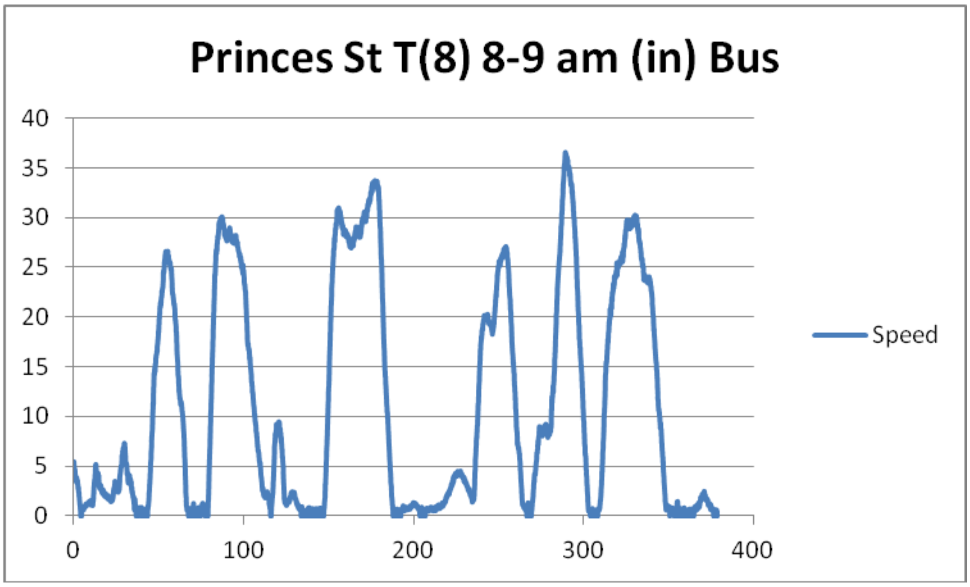


Figure 6.11: The representative driving cycle for buses on bus only corridor (peak hour)

6.8.3.2 Bus driving cycle during off-peak-hours (2.00-3.00 pm) on bus-only corridors

The average driving time for this corridor is 223.855 seconds, the average speed on the corridor is 19.44 km h^{-1} and the average trip length on the corridor is 1206.023 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.19 %, 0.18 %, about 0.142 % and 0.454 % respectively. Figure 6.12 below shows the representative driving cycle for buses on bus only corridor (off peak hour).

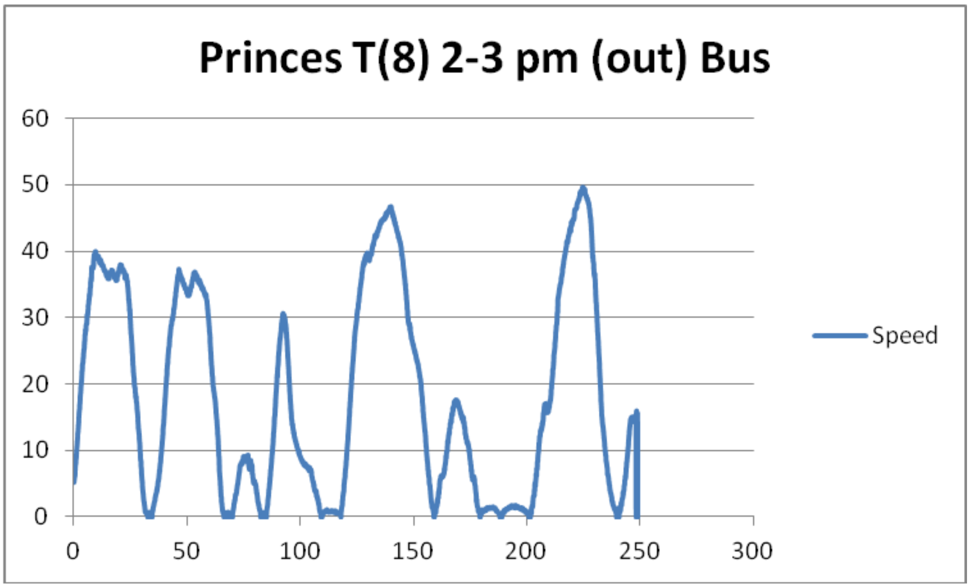


Figure 6.12: The representative driving cycle for buses on bus only corridor (off peak hour)

6.8.4 Development of driving cycles for "Edinburgh traffic calming corridors"

Data was collected over three traffic calming corridors in Edinburgh using an instrumented car. Three corridors were selected with different traffic calming measures and the fourth corridor has no speed reduction measures and was used as a control corridor. The traffic corridors are listed below:

Corridor 1: Iona Street (20 mph zone with speed cushions, speed humps and cobbled street surface)

Corridor 2: West Bryson Road (20 mph zone with speed humps)

Corridor 3: Montgomery Street (20 mph zone with speed humps and raised junctions)

Corridor 4: Polwarth Terrace (20 mph zone with no speed humps). This corridor was considered as the control corridor.

Traffic characteristics on these corridors were analysed and compared and were also compared with traffic characteristics of the control corridor (see Section 7.17). The data sets was analysed to identify the representative driving cycles. Therefore, out of the three corridors there resulted one representative driving cycles for the "Edinburgh traffic calming corridors" as presented in Table 6.6 below. Further discussions, comparisons and analysis of these statistics are presented in Chapter seven.

Table 6.6: Summary statistics of assessment parameters of different Edinburgh traffic calming corridors

The Corridors	Time (sec)	Speed (km/hr)	Distance (meters)	% of acceleration	% of deceleration	% of idling	% of cruising	Sj
Corridor 1	58.59	24.128	392.035	0.177	0.179	0.024	0.618	9.884
Corridor 2	97.735	23.87	643.951	0.173	0.157	0.024	0.64	-6.203
Corridor 3	85.325	27.502	665.676	0.166	0.175	0.019	0.635	-3.681
Corridor 4	55.08	29.127	445.923	0.162	0.134	0.024	0.677	

6.8.4.1 Characteristics of the traffic calming corridor driving cycle

The mean values of the key parameters are presented in Table 6.7 with the derived driving cycles for the representative traffic calming corridor (corridor 2) as well as for control corridor (corridor4). The average driving time on the traffic calming corridor is 97.735 seconds, the average speed on the corridor is 23.87 km h^{-1} and the average trip length on the corridor is 643.951 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.173 %, 0.157 %, about 0.024 % and 0.64 % respectively. Figure 6.13 below show the representative driving cycle for traffic calming corridor.

Table 6.7: Characteristics of the representative driving cycle for traffic calming corridor (corridor 2 vs corridor 4)

The Route		Time (sec)	Speed (km/h)	Distance (meters)	% of acceleration	% of deceleration	% of idling	% of cruising
Corridor 2 (representative driving cycle for traffic calming corridor)	**Average**	97.735	23.87	643.951	0.17375	0.158	0.02	0.64
	SD	9.202	2.148	21.686	0.01281	0.01137	0.01	0.018
	COV	0.094	0.09	0.033	0.073	0.078036	0.47	0.028
Corridor 4 (Control traffic calming corridor)	**Average**	55.08	29.127	445.923	0.162	0.134	0.024	0.677
	SD	3.667	1.112	27.121	0.013	0.011	0.006	0.015
	COV	0.066	0.038	0.06	0.086	0.081	0.257	0.022

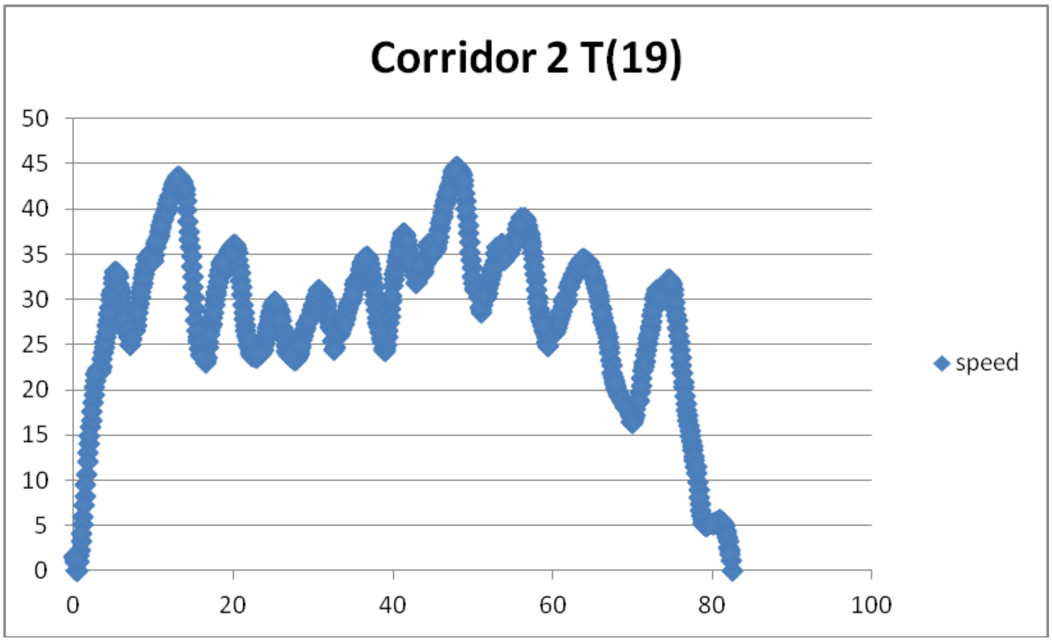


Figure 6.13: The representative driving cycle for traffic calming corridor

From the above data we can see that due to the implementation of a traffic calming system the aims of the instillation were achieved. This is evident from this data as there can be seen to be a decrease in the average speed being observed on the corridor by 5.257 km/hr. This is seen to be a significant decrease as it accounts for 5.5% reduction in the speeds being achieved. As these routes are dominated my slow moving vehicles as it is this accounts for a significant proportional reduction and thus increase in overall safety on the route.

The route of this reduction in speed can be determined through the detailed analysis of the driving behaviour of those using the route. In the control it can be seen that a total of 29.6% of the journeys are spent in the acceleration and deceleration phases, whereas in the calming corridor this figure is increased to a total of 33.175% of the journey time. This alteration in percentage journey time represents a significant change in driving style given that overall lower speeds are being achieved. This data along with an apparent reduction in overall percentage time spent in the idling and cruising phases would lead us to believe that the implementation of the calming system has led to much more sporadic and uneven driving styles being adopted while in turn reducing the overall speeds being achieved. This would in turn lead us to infer that the most likely system which has been introduced has been the instillation of speed ramps which deem it necessary for vehicles to decelerate on approach but do not require the vehicle to come to a complete stop thus resulting in an overall increase in the deceleration percentage of the vehicle without altering idling time. There is also a requirement to accelerate following the calming measure however the obstructions are often placed at intervals to reduce as much as the maximum speed of the vehicle. Due to this there will be seen an increase in the overall percentage of the journey dedicated to acceleration along with a decrease in cruising times on the given route.

6.9 Development of driving cycles for “Abu Dhabi traffic corridors”

Data collection was carried out using a GPS, a performance box and data logging equipment, while travelling by car and on the buses on the selected mixed traffic corridors in Abu Dhabi, during peak and off peak hours, inbound (I) and outbound (O) the selected corridors (the Airport Road and the Elektra Road). See Section 3.4.3 for details of method of data collection and Section 5.4 for the preliminary data analysis.

Representative driving cycles were selected for each traffic corridor type from each of the inbound and outbound data sets. Table 6.8 below shows the summary statistics of the driving cycle of each of the corridors.

Table 6.8: Summary statistics of the driving cycle of each of the corridors in Abu Dhabi

Route	Time	Mode	Direction	Average Time	Average Speed	Average Length	% time of Acc	% time of Dec	% time of Idling	% time of Cruising	Sj
Airport Road	**6.30.7.30 Am**	**Car**	**Inbound**	252.64	35.628	2387.998	0.206	0.175	0.143	0.472	-1.034
			Outbound	171.96	44.832	2089.216	0.208	0.15	0.071	0.566	3.403
		Bus	**Inbound**	544.9	15.61	2331.912	0.186	0.173	0.302	0.335	-8.313
			Outbound	422.8	19.907	2302.241	0.181	0.139	0.267	0.409	-2.796
	11.00-12.00 Am	**Car**	**Inbound**	188.35	45.609	2364.854	0.203	0.159	0.074	0.56	1.011
			Outbound	167.9	33.284	1573.809	0.194	0.148	0.141	0.513	7.777
		Bus	**Inbound**	437.42	19.127	2248.493	0.187	0.124	0.258	0.427	-1.914
			Outbound	332.17	25.765	2359.612	0.202	0.12	0.161	0.513	1.867
Elektra Road	**6.30-7.30 Am**	**Car**	**Inbound**	209.69	30.552	1762.837	0.187	0.112	0.245	0.452	-0.321
			Outbound	176.4	35.553	1718.947	0.19	0.07	0.191	0.545	2.789
		Bus	**Inbound**	323.077	20.502	1819.247	0.179	0.154	0.196	0.467	-2.48
			Outbound	397.9	16.873	1840.797	0.172	0.128	0.268	0.428	-3.085
	11.00-12.00 Am	**Car**	**Inbound**	203.033	33.459	1789.443	0.205	0.116	0.227	0.448	-1.68
			Outbound	207.777	27.737	1572.042	0.181	0.122	0.263	0.43	1.106
		Bus	**Inbound**	291.47	20.636	1649.049	0.195	0.164	0.199	0.438	-1.349
			Outbound	342.71	15.376	1444.897	0.154	0.073	0.309	0.459	5.021

6.9.1 Characteristics of the Airport road corridor driving cycle

The mean values of the key parameters are presented in Table 6.8 with the derived driving cycles for the representative driving cycles as discussed above. The characteristics of the representative driving cycles are discussed briefly below. Further discussions, comparisons and analysis of these statistics are presented in Chapter Seven.

6.9.1.1 Peak-hour (6.30-7.30 am) (outbound) driving cycle for cars on Airport Road corridor

The average driving time for this corridor is 252.64 seconds, the average speed on the corridor is 35.628 km h^{-1} and the average trip length on the corridor is 2387.998 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.206 %, 0.175 %, about 0.143 % and 0.472 % respectively. Figure 6.14 below shows the representative driving cycle for cars on mixed traffic corridor (Airport Road) (peak hour).

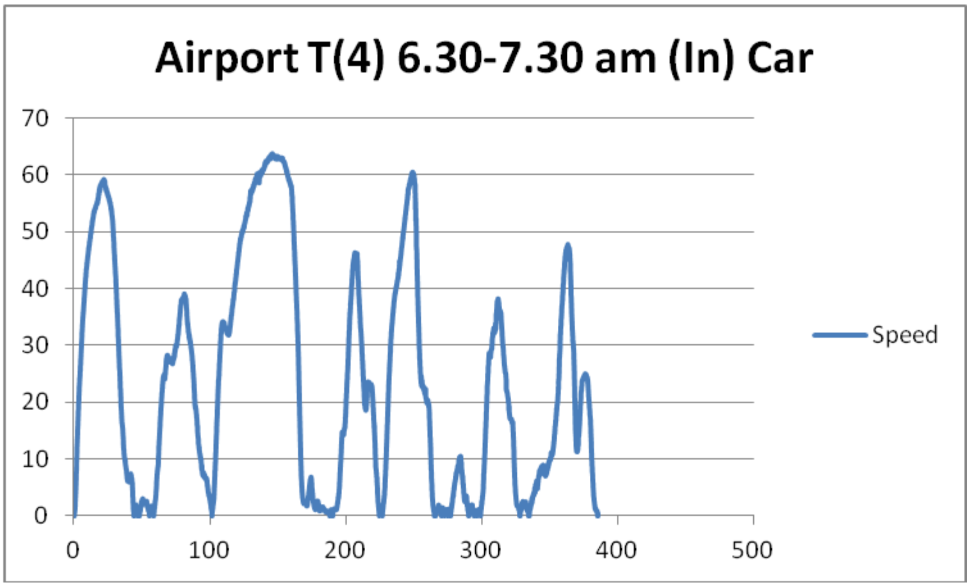


Figure 6.14: The representative driving cycle for cars on mixed traffic corridor (Airport Road) (peak hour)

6.9.1.2 Off Peak-hour (11.00 am-12.00 pm) (inbound) driving cycle for cars on Airport corridor

The average driving time for this corridor is 188.35 seconds, the average speed on the corridor is 45.609 km h^{-1} and the average trip length on the corridor is 2364.854 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.203 %, 0.159 %, about 0.074 % and 0.56 % respectively. Figure 6.15 below show the representative driving cycle for cars on mixed traffic corridor (Airport Road) (off peak hour).

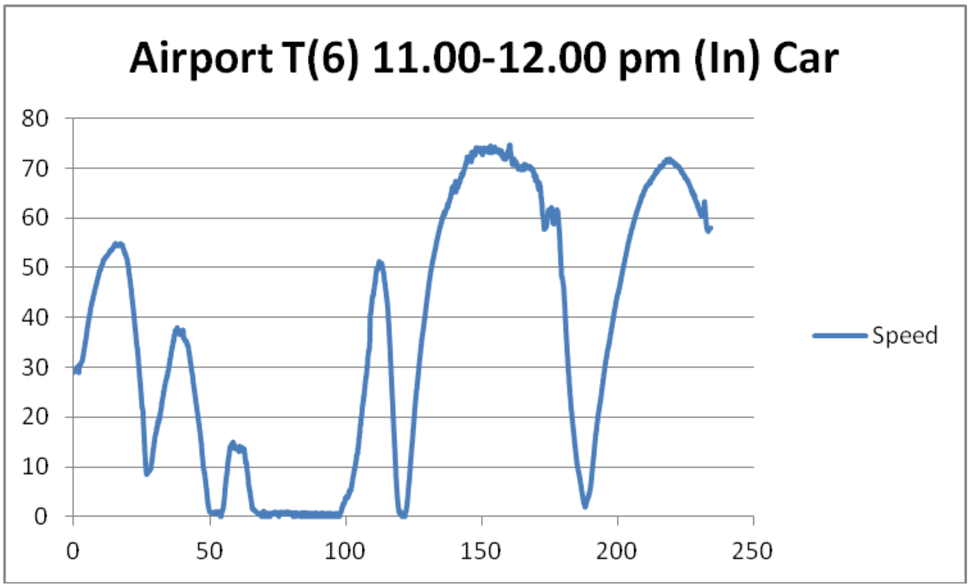


Figure 6.15: The representative driving cycle for cars on mixed traffic corridor (Airport Road) (off peak hour)

6.9.1.3 Peak-hour (6.30-7.30 am) (outbound) driving cycle for buses on Airport Road corridor

The average driving time for this corridor is 544.9 seconds, the average speed on the corridor is 15.61 km h^{-1} and the average trip length on the corridor is 2331.912 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.186 %, 0.173 %, about 0.302 % and 0.335 % respectively. Figure 6.16 below shows the representative driving cycle for buses on mixed traffic corridor (Airport Road) (peak hour).

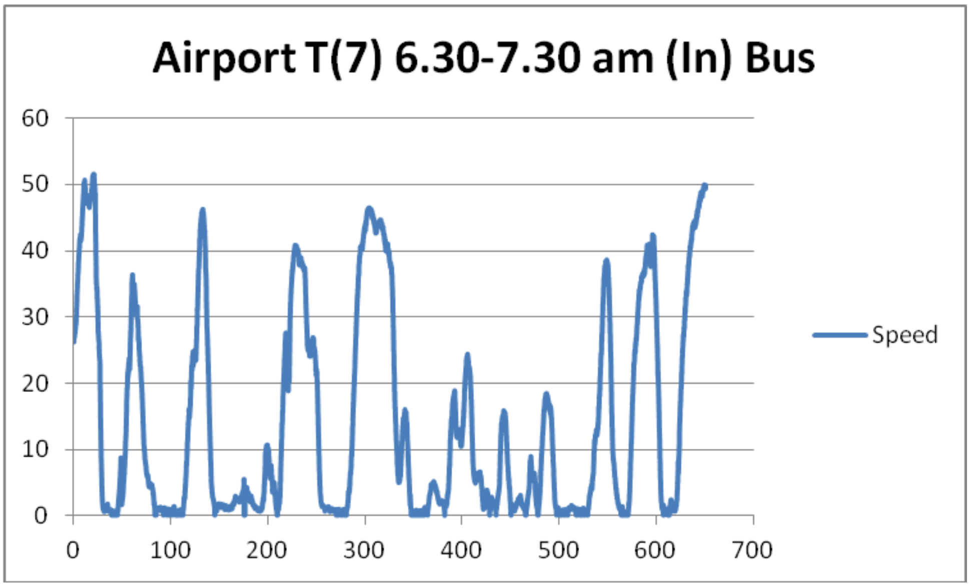


Figure 6.16: The representative driving cycle for buses on mixed traffic corridor (Airport Road) (peak hour)

6.9.1.4 Off Peak-hour (11.00 am-12.00 pm) (inbound) driving cycle for buses on Airport Road corridor

The average driving time for this corridor is 437.42 seconds, the average speed on the corridor is 19.127 km h^{-1} and the average trip length on the corridor is 2248.493 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.187 %, 0.124 %, about 0.258 % and 0.427 % respectively. Figure 6.17 below shows the representative driving cycle for buses on mixed traffic corridor (Airport Road) (off peak hour).

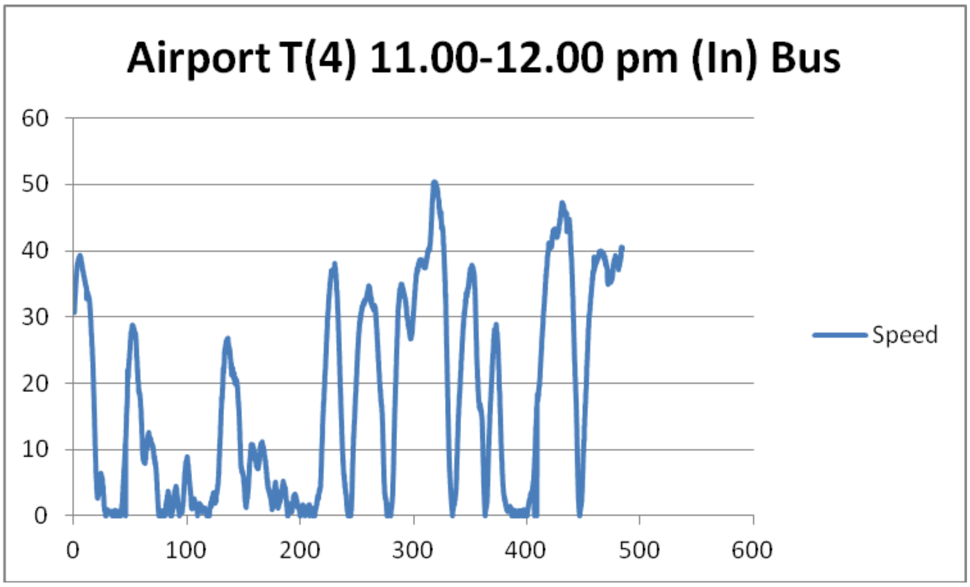


Figure 6.17: The representative driving cycle for buses on mixed traffic corridor (Airport Road) (off peak hour)

6.9.2 Characteristics of the Elektra Road corridor driving cycle

The mean values of the key parameters are presented in Table 6.8 with the derived driving cycles for the representative driving cycles as discussed above. The characteristics of the representative driving cycles are discussed briefly below. Further discussions, comparisons and analysis of these statistics are presented in Chapter seven.

6.9.2.1 Peak-hour (6.30-7.30 am) (inbound) driving cycle for cars on Elektra Road corridor

The average driving time for this corridor is 209.69 seconds, the average speed on the corridor is 30.552 km h^{-1} and the average trip length on the corridor is 1762.837 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.187 %, 0.112 %, about 0.245 % and 0.452 % respectively. Figure 6.18 below shows the representative driving cycle for cars on mixed traffic corridor (Elektra Road) (peak hour).

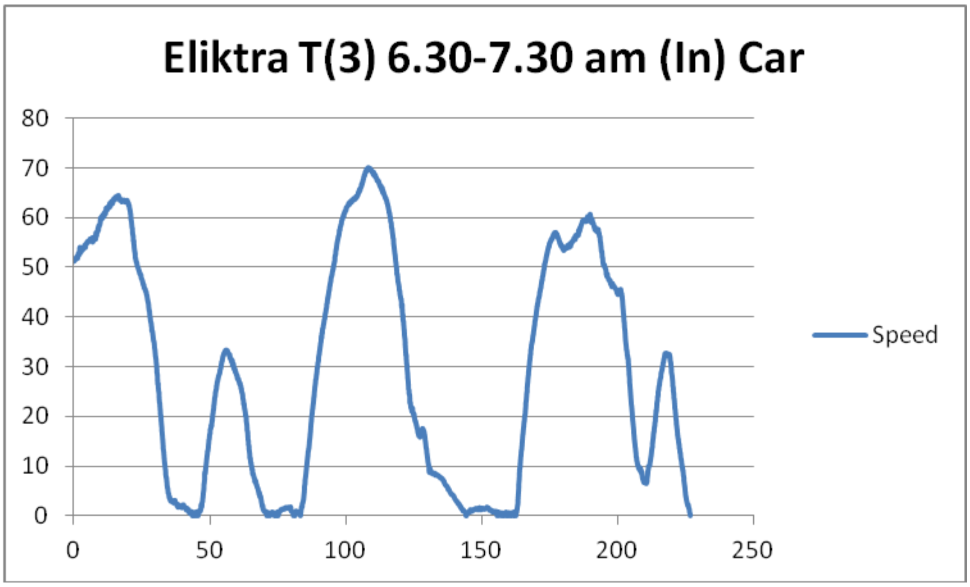


Figure 6.18: The representative driving cycle for cars on mixed traffic corridor (Elektra Road) (peak hour)

6.9.2.2 Off Peak-hour (11.00 am-12.00 pm) (inbound) driving cycle for cars on Elektra Road corridors

The average driving time for this corridor is 203.033 seconds, the average speed on the corridor is 33.459 km h^{-1} and the average trip length on the corridor is 1789.443 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.205 %, 0.116 %, about 0.227 % and 0.448 % respectively. Figure 6.19 below shows the representative driving cycle for cars on mixed traffic corridor (Elektra Road) (off peak hour).

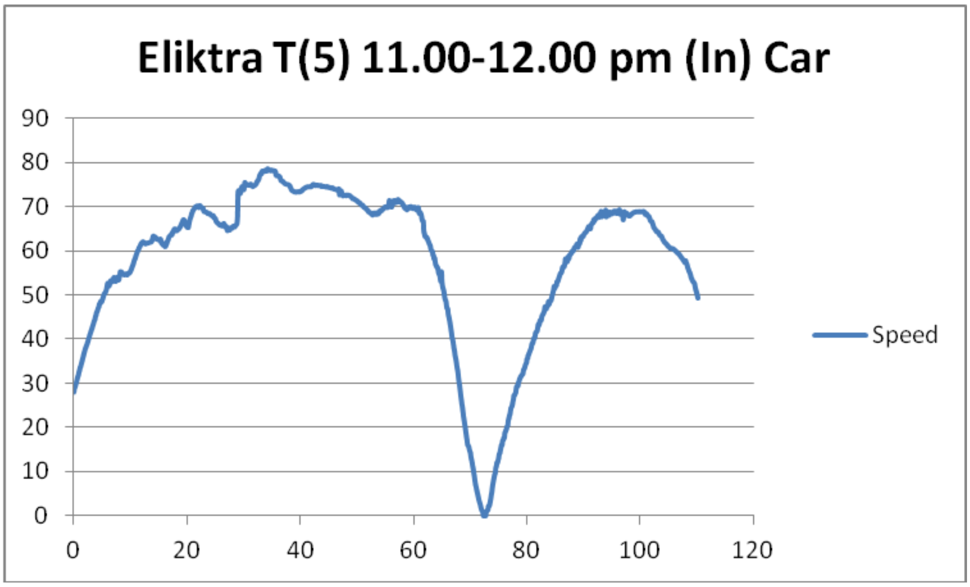


Figure 6.19: The representative driving cycle for cars on mixed traffic corridor (Elektra Road) (off peak hour)

6.9.2.3 Peak-hour (6.30-7.30 am) (outbound) driving cycle for buses on Elektra Road corridor

The average driving time for this corridor is 397.9 seconds, the average speed on the corridor is 16.873 km h^{-1} and the average trip length on the corridor is 1840.797 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.172 %, 0.128 %, about 0.268 % and 0.428 % respectively. Figure 6.20 below shows the representative driving cycle for buses on mixed traffic corridor (Elektra Road) (peak hour).

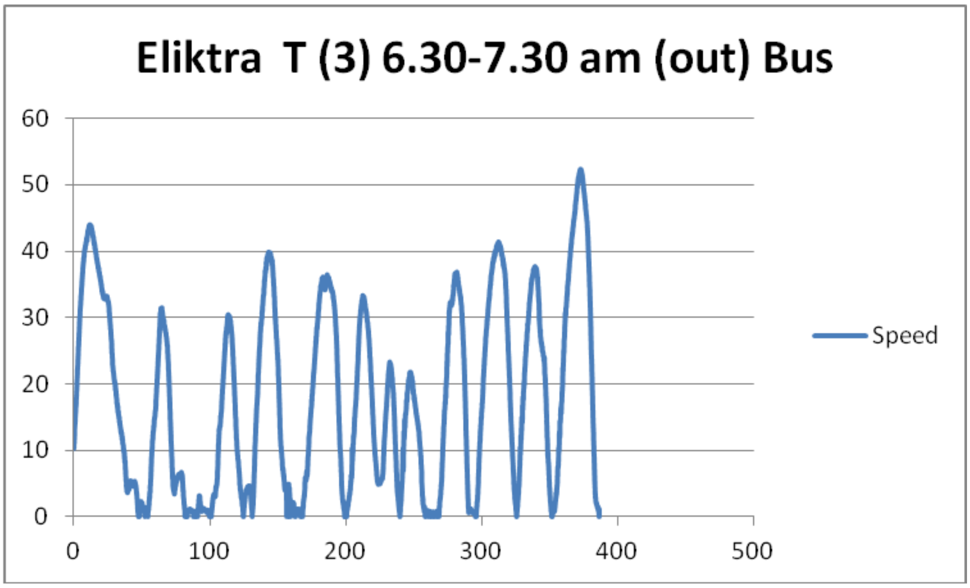


Figure 6.20: The representative driving cycle for buses on mixed traffic corridor (Elektra Road) (peak hour)

6.9.2.4 Off Peak-hour (11.00 am-12.00 pm) (outbound) driving cycle for buses on Elektra Road corridor

The average driving time for this corridor is 291.47 seconds, the average speed on the corridor is 20.636 km h^{-1} and the average trip length on the corridor is 1649.049 meters. The % time spent on acceleration, deceleration, idling and cruising on the corridor is 0.195 %, 0.164 %, about 0.199 % and 0.438 % respectively. Figure 6.21 below shows the representative driving cycle for buses on mixed traffic corridor (Elektra Road) (off peak hour).

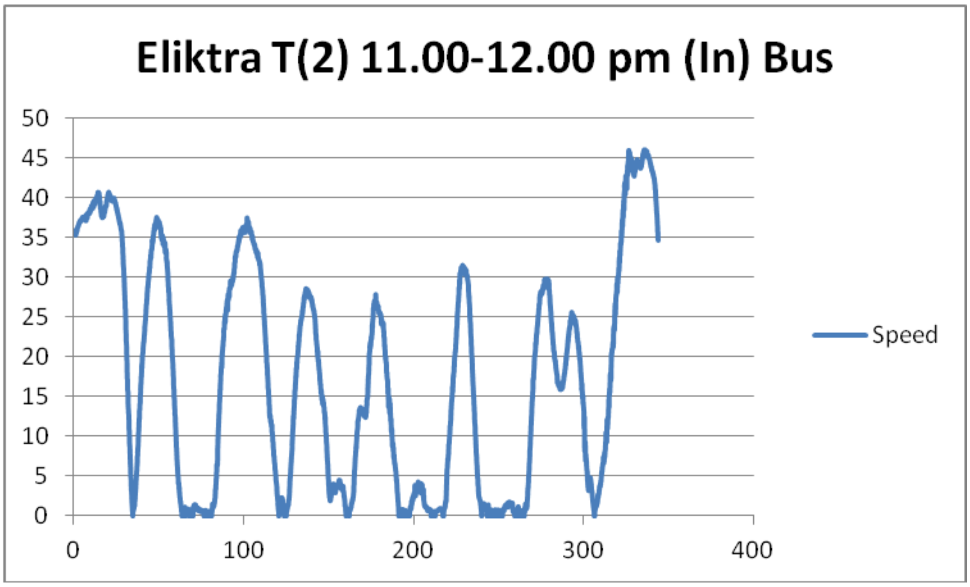


Figure 6.21: The representative driving cycle for buses on mixed traffic corridor (Elektra Road) (off peak hour)

6.10 Summary

In this section the summary statistics of the results produced from driving cycle analysis have been presented. A more detailed analysis of these results will be discussed and compared in the following chapter. That will include investigations of the variations taking place on individual corridors and attempt to justify the reasons for these variations. The statistics which are to be examined include; journey time, average speed, % time spent accelerating, % time decelerating, % time Idling and % time cruising. The parameters for the determination of these statistics have been clearly outlined in Section 6.2. In addition, a comparison of these statistics for individual corridors will also be discussed in order to determine the most efficient corridor type available. i.e. is a bus lane road more efficient than a no bus lane road or a bus only road.

CHAPTER 7

ANALYSIS AND COMPARISON OF THE RESULTS OF DRIVING CYCLES

7.1 Introduction

In this section a more in-depth and detailed analysis of the preliminary results produced from the data on driving cycles developed in Chapter Five and Chapter Six above shall be carried out. The purpose of this shall be to examine any variations taking place on individual corridors and attempt to justify the reasons for these variations. The statistics which are to be examined include; journey time, average speed, % time spent accelerating, % time decelerating, % time idling and % time cruising. The parameters for the determination of these statistics have been clearly outlined in Section 6.2.

Along with carrying out an analysis of these statistics for individual corridors, comparisons shall also take place between the corridors as a whole in an attempt to determine the most efficient corridor type available. i.e. is a bus lane road more efficient than a no bus lane road or a bus only road.

7.2 Analysis of the performance of buses on the bus lane road in Edinburgh

Table 7.1: Summary statistics of bus driving cycle parameters on the A7, Edinburgh

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A7 (bus lane road)	8.00-9.00 Am	354.2	15.29	1482.013	0.195	0.147	0.259	0.396
	2.00-3.00 Pm	365.23	14.759	1474.767	0.188	0.133	0.248	0.427
	6.30-7.30 Am	259.788	19.989	1396.928	0.161	0.106	0.162	0.567

The table above presents the data to be analysed for the buses travelling on A7 (bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

From this data we can see that the off peak journey time for this corridor is 3.1% higher than that of the peak journey time. This may be due to the fact that there may be increased pedestrian and cyclist activity within this lane during the off peak which may cause obstructions and delays to the vehicles. This along with the fact that the bus lane is only in operation at certain times of the day means that there will also be inherent interference with the free movement of the buses due to the presence of other vehicles on the corridor.

When comparing the off peak and peak journeys it can be seen that the total percentages of the journeys which are dedicated to acceleration and deceleration are 32.1% and 34.2% respectively. When this information is taken into account and used as basis for comparison of the total times spent in cruising and idling it is clear that there is a much more unobstructed movement of buses in the off peak time. Even though the overall journey time is increased slightly there is a greater percentage of the journey spent in motion and less of it spent idling. The reasons for this increase in efficiency when the bus lane is not in effect are numerous, however the most likely factor which effects it is that there is an overall reduction in the volume of customers availing of the bus service at this time and thus there is a reduction in the amount of time spent at each stop letting people on and off the bus, along with a reduction in the number of stops necessary to be made. This along with the possibility of increased bus numbers operating along the corridor at these times will result in an overall reduction in cruising time.

It can be seen that all observed readings are more favourable in the early morning time period before the bus lane takes effect. There is a reduction in journey time for this period of 26.7% when compared to the peak time when the bus lane is in operation, which is clearly seen due to the significant increase of 7.399km/hr in average speed occurring throughout the corridor. It can be seen that during this time period that there is a greatly reduced overall percentage of the journey dedicated to acceleration and deceleration at only 26.7% and idling falling to 16.2% and cruising rates increasing to 56.7%. These alterations in the statistics are likely due to the significantly lower volumes of traffic travelling on the corridor at this time of the day, along with a reduction in the number of stops being made by the buses due to an overall reduction in patron numbers.

Due to the above information at first glance it may be interpolated that the implementation of the bus lane does in fact reduce the efficiencies of the buses along this corridor however the overall effect of this implementation cannot be fully assessed until such time as the effects this lane has on other vehicles using the route.

7.3 Analysis of the performance of buses on the no bus lane road in Edinburgh

Table 7.2: Summary statistics of bus driving cycle parameters on the A702, Edinburgh

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A702 (no bus lane road)	**8.00-9.00 Am**	350.99	16.401	1563.981	0.144	0.081	0.265	0.506
	2.00-3.00 Pm	358.811	16.758	1646.576	0.148	0.077	0.249	0.515

The table above presents the data to be analysed for the buses travelling on A7025 (no bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

From this we can see that there is a slight increase in journey time of 7.82 seconds for the off peak journey time when compared to the peak journey time. This is however contrary to the average speed data whereby the traffic is flowing at an average of 0.357 km/hr faster in the off peak time period. The reasoning behind this discrepancy in the data is due to the fact that the route observed in the peak time period is in fact on average 82.6 metres shorter than the one examined in the off peak time period. When this is allowed for and the length of the off peak journey time is adjusted to have a same length as the peak journey and assuming a similar average speed we see that the overall journey time can be interpolated as being 341.066 seconds. This is in line with the expected results for the observations given that there will invariably be a reduction in overall traffic flows and passenger numbers during the off peak time period.

When an analysis of the driver behaviour is carried out we can see that a slightly higher percentage of the journey time is spent in acceleration during the off peak hours (14.8%) which is to be expected as a slightly higher average speed is achieved. The percentage of time spent in deceleration however is slightly lower (7.7%) in this time period when compared to the peak time (8.1%). This would lead us to believe that the driver is taking an overall more aggressive approach to their driving style which may be down to a reduction in overall traffic volumes and thus a belief that the road conditions will allow for a more aggressive style.

We can see also that there is a decrease and increase in the percentages spent in idling and cruising in the peak time period (24.9% and 51.5% respectively) when compared to the off peak time period (26.5% and 50.6%). Both of these changes in the overall percentage of the journey time spent in these situations leads us to believe that there is a higher traffic volume on the route at this time. This may take the form of both other vehicles on the route along with a higher number of pedestrians and patrons of the bus services. All of these factors would require the busses to be stationary for much longer periods of time at signalised junctions, pedestrian crossings and bus stops.

7.4 Analysis of the performance of buses on the bus only road in Edinburgh

Table 7.3: Summary statistics of bus driving cycle parameters on Princes Street, Edinburgh

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Princes St (bus only road)	8.00-9.00 Am	286.52	14.426	1091.004	0.196	0.198	0.25	0.352
	2.00-3.00 Pm	223.855	19.44	1206.023	0.19	0.18	0.142	0.454

The table above presents the data to be analysed for the busses travelling on Princes Street (bus only road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

As has been stated previously this is a very unusual route as the route is a bus and taxi only route and it was deemed prudent to carry out an examination of this route as part of this research as so few of these roadways exist.

We can see for the data provided as to the details of the journey distances being compared along with the average speeds achieved and journey times that the off peak journey is significantly quicker than that of the peak journey. What makes this difference in overall journey time even more significant is the fact that there was a difference of 115.1 metres in the overall distance of the corridor being examined. Should the average time be adjusted in line with the average speed observed for the off peak journeys and assuming that the average length of the journey is the same as the peak journey we can interpolate the journey should take a total of 202.038 seconds which represents a significant time saving between the two time periods.

However it is once more essential to examine the actual driving behaviour of those using the route and not just rely on average journey times in the assessment of the overall route. It would be expected that the peak time for the journey will be significantly higher due to the increased number of passengers on the route which will lead to an increase in time spent stationary. This can clearly be seen in the data provided for the idling times of the buses where an increase of 10.8% of the journey time in the peak time is seen when compared to the off peak time along with a decrease of 10.2% in the overall time spent cruising. This may also be due to a significant increase in the overall traffic volumes at the peak time, which in turn will lead to the need for queuing of the buses to take place at the stops at times of heavy passenger numbers.

It is also clear that the drivers behave in a slightly more aggressive manner when accelerating and decelerating in the off peak times. This is evident in the fact that a lower percentage of the total journey time is spent in these actions during the off peak time (37%) when compared to the peak time (39.4). This decrease in time spent in altering the speed of the buses along with the fact that higher overall average speeds are being achieved would indicate that these top speeds are reached and slowed from at a much greater rate. This may be once more due to an overall reduction in traffic volumes operating on the route and thus the drivers deem it to be a much safer time to be travelling on the route and thus a more aggressive manner may be adopted.

7.5 Analysis of the performance of cars on the bus lane road in Edinburgh

The table below presents the data to be analysed for the cars travelling on the A7 (bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.4: Summary statistics of car driving cycle parameters on the A7, Edinburgh

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A7 (bus lane road)	8.00-9.00 Am	232.555	23.401	1480.22	0.187	0.178	0.11	0.52
	2.00-3.00 Pm	291.92	19.245	1531.861	0.191	0.178	0.144	0.483
	6.30-7.30 Am	169.922	32.39	1489.863	0.178	0.169	0.061	0.588

From the above data we can see that there is a drastic increase in the overall efficiency of the road when the bus lane is in operation during the peak time when compared to the off peak time. There is a significantly lower journey time taking place during the before 7:30 time period when the bus lane is also not in use, however this vast reduction in journey time may be attributed to the overall reduction in traffic volumes on the route.

For the examination of the off peak flow we can see that a corridor which was 51.64 metres on average was being travelled on at a lower speed than at peak flow times. When this data is adjusted to allow for this same speed to be carried out over a similar distance we can see that a total journey time of 281.69 seconds is achieved which is still a greater time than that of the off peak time. It is clear from this that the inclusion of the bus lane does reduce the overall journey time for the car users on the route.

The overall benefits of the inclusion of this lane for the car users may be seen in the fact that the overall percentage of the journey spent accelerating decreases from 19.1% to 18.7% when the bus lane is in place, this may be due to the fact that there is less of an occurrence of the cars being caught behind the slower accelerating buses which are required to use the non-bus lane when the bus lane is congested with other traffic. The percentage of journey time spent in deceleration during these two time periods is identical however which would lead us to believe that there is no significant alteration in the driving style of the vehicle occupants during these two time periods.

It can also be seen that there is a decrease and increase in the percentages of the journey spent idling and cruising respectively when the bus lane is in effect as opposed to when all traffic is able to use it. This is due to the ability of the cars to freely segregate themselves from the buses which may be required to encroach onto the lanes which they occupy during these times as other road users may be using the bus lane and causing an obstruction for the busses.

7.6 Analysis of the performance of cars on the no bus lane road in Edinburgh

Table 7.5 below presents the data to be analysed for the cars travelling on the A702 (no bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.5: Summary statistics of car driving cycle parameters on the A702, Edinburgh

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A702 (no bus lane road)	8.00-9.00 Am	276.122	22.051	1650.357	0.169	0.104	0.165	0.544
	2.00-3.00 Pm	318.82	19.234	1622.052	0.155	0.103	0.207	0.531

From the above data it can be seen that there is a significantly higher journey time on this route for all car users during the off peak time than during the peak time. This is counter intuitive as one would expect a greater volume of traffic to lead to an increase journey time over this route. This would in turn lead us to believe that there may be an extremely efficient traffic management system taking place along this corridor which will alter the green time displayed to this road during times of heavy traffic flow and thus helping to alleviate congestion.

This hypothesis may be further supported through the analysis of the driver behaviour on the route. This indicates that even though there is a significantly lower percentage of the overall journey time spent idling, when this is compared with the figures for when the vehicles are accelerating and at cruising speeds there is a significant increase in these activities when compared to the off peak time period. This would lead us to believe that there is a much more controlled and freer flow of traffic taking place.

This hypothesis may be false however as this route may not in fact experience higher flows of traffic in the traditional morning peak time, should this be a mainly residential area, which does not provide a main link to areas of high population and high employment it is possible that the majority of the traffic delay is experienced at other times of the day. This may be what is occurring in this situation as the 4.2% increase in idling time may also reflect a higher overall congestion rate due to higher traffic volumes. The presence of a school along or near this route may also be having an effect on these results as this would lead to a significant increase in pedestrian and vehicle numbers during this off peak period.

7.7 Analysis of the performance of cars and buses on the bus lane road in Edinburgh

Table 7.6 presents the data to be analysed for the cars and buses travelling on the A7 (bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.6: Summary statistics of car and bus driving cycle parameters on the A7, Edinburgh

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A7 (bus lane road)	**8.00-9.00 am**	Bus	354.2	15.29	1482.013	0.195	0.147	0.259	0.396
		Car	232.555	23.401	1480.22	0.187	0.178	0.11	0.52
	2.00-3.00 pm	Bus	365.23	14.759	1474.767	0.188	0.133	0.248	0.427
		Car	291.92	19.245	1531.861	0.191	0.178	0.144	0.483
	6.30-7.30 am	Bus	259.788	19.989	1396.928	0.161	0.106	0.162	0.567
		Car	169.922	32.39	1489.863	0.178	0.169	0.061	0.588

From the data presented in the above table it can be seen that in all instances there is a significant reduction in journey time when using cars as opposed to buses as the method of transportation. It can also be seen that higher average speeds are achieved at all times by cars than buses with the greatest variation in this respect taking place in the before 7:30 time period where a difference of an average of 12.4km/hr can be seen. In this time period it is seen that even though relatively equal percentages of the journey are spent in the cruising and acceleration phases of the journey for the two vehicle types there is an ability of the car driver to achieve and maintain these speeds much quicker.

We can also see that when the bus lane is in operation the cars are capable of achieving a rate of 52% of the journey at cruising rates in comparison to the 39.6% achieved by the buses. This along with increased idling times for the buses both contribute to the lower average speed and thus higher journey time of the buses.

Therefore, it is clear that the car speed is much higher than that of the buses on the bus lane corridor during peak and during off peak hours (53% & 30%) respectively. In terms of idling times, it is also seen that the bus spend much more higher time idling than the cars during both peak and off peak times (135% & 72.2% higher idling times) respectively. In terms of cruising times, it is also seen that the bus spends much less time cruising than the cars during both peak and off peak times (31.3% & 13.1% higher cruising times) respectively. In the scenario of the before the bus lane operation, that is between 6.30 and 7.30 am, the bus performance relative to that of the cars is also similar. That is the idling times for the bus is 165% higher than that of the cars while the cruising times are similar

We can then see that once the bus lane is no longer in use there is a falloff in the overall journey times of all vehicles on the route. This may be due to overall higher traffic and pedestrian rates, however this is unlikely. The lack of a bus lane could also be a likely factor for these delays with vehicles being forced to interact with each other to a greater extent when the bus lane is in effect. This lack of a bus lane has an effect on the traffic stream as a whole with a reduction in the deviation for all parameters being examined between both forms of transport. This would lead us to believe that there is a much more uniform traffic flow present but we must attempt to determine to what extent this is hindering the free movement of the cars on the corridor and if this is in fact the most efficient method available.

There may be grounds also to claim that the presence of the bus lanes do not necessarily brings advantages to the buses. This might be because of the fact that buses are forced to queue up in the bus lane and are not free to overtake other traffic and leave the queue which might results in higher idling times for buses than they are for cars for example. Further research in this direction is certainly needed.

7.8 Analysis of the performance of cars and buses on the no bus lane road in Edinburgh

Table 7.7 presents the data to be analysed for the cars and buses travelling on the A702 (no bus lane road) within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.7: Summary statistics of car and bus driving cycle parameters on the A702, Edinburgh

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A702 (no bus lane road)	8.00-9.00 Am	Bus	350.99	16.401	1563.981	0.144	0.081	0.265	0.506
		Car	276.122	22.051	1650.357	0.169	0.104	0.165	0.544
	2.00-3.00 Pm	Bus	358.811	16.758	1646.576	0.148	0.077	0.249	0.515
		Car	318.82	19.234	1622.052	0.155	0.103	0.207	0.531

From the data above we can see that there is a significant reduction in journey time along with an increase in average speed for car users along this corridor as a whole. Once more we must infer from the data above that there is in fact a higher traffic flow at the off peak time than at the peak time due to the overall increase in journey time for all vehicles.

We do see however that in the off peak time there is a reduction in the overall percentage of time spent by the car users cruising, and this in turn is reflected in an increase in this aspect for buses. We also see that there is an increase in idling time for car users during the off peak time whereas there is an overall reduction in this aspect for the buses. All of this data would lead us to believe that the car users are being delayed more by the busses during this time period. The reason for this may be that due to increased oncoming traffic flows there are not as many opportunities for the car to overtake the bus when it is stationary at bus stops. This is further reflected in the fact that the cars percentage of time in acceleration is altered in the off peak time to mirror more closely that of the bus than was evident in the peak flow data.

It is most prudent to realise however that no major alterations in the overall style of driving take place for the bus users during these two time frames, however when these figures are compared to those of the car users it can be seen that overall the journey times are increased with the average speed being reduced. This along with the increased idling times experienced along with increased time spent in acceleration can possibly lead to impatience on behalf of the car driver along with increased anger at perceived delays.

7.9 Analysis of the performance of buses on the bus lane road and no bus lane road in Edinburgh

Table 7.8 presents the data to be analysed for the buses travelling on the A7and A702 roads within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.8: Summary statistics of bus driving cycle parameters on the A7 and A702, Edinburgh

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A7 (bus lane road)	8.00-9.00 Am	Bus	354.2	15.29	1482.013	0.195	0.147	0.259	0.396
	2.00-3.00 Pm	Bus	365.23	14.759	1474.767	0.188	0.133	0.248	0.427
A702 (no bus lane road)	8.00-9.00 Am	Bus	350.99	16.401	1563.981	0.144	0.081	0.265	0.506
	2.00-3.00 Pm	Bus	358.811	16.758	1646.576	0.148	0.077	0.249	0.515

From the above data we may ignore the average time taken and average speed as the information provided is for two different routes whose conditions are too varied to accurately compare for driving time and speed. The purpose of this analysis is to examine the overall effect the implementation and presence of a bus lane has on the driving styles achieved by the road users, in this case busses.

From this data we can see that on the A7 during the times when the bus lane is in effect there is in fact more of a restriction in the amount of time spent cruising by the buses. This time is not however directly transferred to the idling time but instead is associated more with the acceleration and deceleration phases of the journey. This would indicated that while there is an overall reduction in the amount of time spent at a constant speed there is in effect an increase in the overall time spent in motion. When this is compared to the A702 for the same time period we can see that there is a greater percentage of the overall journey spent in the idling phase. However as this represents only a 0.6% difference it is hard to verify the reasons for this change in behaviour. This could be down to a slightly higher number of passengers availing of the bus service along this route at this time. From this we can see that there is no clear advantage to the implementation of the bus lane to help to speed up the flow of the buses on these routes. It can be envisaged if a bus lane was to be implemented on the A702 there would also be little or no benefit to the buses efficiency, however the benefits that it may provide to the other road users is also a vital benefit.

7.10 Analysis of the performance of cars on the bus lane road and no bus lane road in Edinburgh

Table 7.9: Summary statistics of car driving cycle parameters on the A7 and A702, Edinburgh

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
A7 (bus lane road)	8.00-9.00 Am	Car	232.555	23.401	1480.22	0.187	0.178	0.11	0.52
	2.00-3.00 Pm	Car	291.92	19.245	1531.861	0.191	0.178	0.144	0.483
A702 (no bus lane road)	8.00-9.00 Am	Car	276.122	22.051	1650.357	0.169	0.104	0.165	0.544
	2.00-3.00 Pm	Car	318.82	19.234	1622.052	0.155	0.103	0.207	0.531

Table 7.9 presents the data to be analysed for the cars travelling on the A7 and A702 roads within Edinburgh city. These statistics have been extracted from Table 6.5 and have been selected as they represent the data collected with the lowest relative errors.

From the above data we may ignore the average time taken and average speed as the information provided is for two different routes whose conditions are too varied to accurately compare for driving time and speed. The purpose of this analysis is to examine the overall effect the implementation and presence of a bus lane has on the driving styles achieved by the road users in this case cars.

From the above data we can see that due to the implementation of the bus corridor in the peak time on the A7 there is an increase in the overall time spent in motion by the cars travelling on this route when compared to that of the off peak time. This is most likely due to the presence of the bus lane at this time removing the buses from the main thoroughfare and providing them with their own lane and thus eliminating any possible conflicts between the two transport modes.

It can also be seen that when a comparison is made between the two different routes at the same time periods that there is a significantly higher percentage of the cars journey spent in the idle phase on the A702. This may be attributed also to the fact that there is no bus lane provided on this route and thus there is a reduced opportunity for the cars to overtake these buses when they are required to stop to pick up passengers. It can also be seen however that the overall percentage of time spent in the cruising phase on the A702 is higher than on the A7 with lower total acceleration and deceleration times present also. This would lead us to believe that the aim and the implementation of bus lanes should be revisited in order for this policy to meet its targets.

This data may all lead us to believe that there is in fact no necessity to implement a bus lane on the A702 and should this take place at any stage a detailed analysis of the data collected to justify its implementation should be carried out. This provides us with a strong argument that it is not always going to be an improvement to an overall road network to implement a bus lane.

7.11 Analysis of the performance of buses on the Airport Road in Abu Dhabi

Table 7.10 presents the data to be analysed for the buses travelling on the Airport Road within Abu Dhabi. These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.10: Summary statistics of bus driving cycle parameters for Airport Road, Abu Dhabi

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Airport Road	6.30.7.30 Am	544.9	15.61	2331.912	0.186	0.173	0.302	0.335
	11.00-12.00 Am	437.42	19.127	2248.493	0.187	0.124	0.258	0.427

From the above data we can see that there is a significant difference in the average time taken to complete the route by the buses for the given time periods. This difference can be slightly mitigated when we adjust the average time to account for the difference in the length of the corridor under examination in the two situations. Given that in the off peak time period the corridor is in fact shortened by 83.419 meters, should we adjust the average time taken to account for this discrepancy we see that the duration adjusts to 453.12 seconds. This still is however a significant difference in time taken to complete the same route. This clearly indicates to us that there are extremely different conditions present in the two time periods.

Given that the percentages of time spent in acceleration are virtually identical in the two time periods it along with the fact that the percentage of time spent decelerating is 4.9% lower in the off peak time we can infer from this that the driver is capable of adopting a more aggressive driving style. This would lead us to believe that there is much less congestion on the route as the driver feels safe in the adoption of this driving style.

It can also be seen that the idling times are 4.4% higher in the peak time. This indicated that the buses were required to spend a much greater time stationary throughout the corridor in this time period. The reasons for this may be that due to increased traffic flows there are larger queues forming at signalised junctions. These higher delays may also be due to increased passenger numbers availing of the buses on the corridor at this time which would require a greater duration spent at each stop to allow for the alighting of this greater volume of people.

It is also clear that a much freer movement of the vehicles is allowed during the off peak time period due to the fact that there is an increase of 9.2% of the journey time in the cruising phase when compared to the peak time. This would also indicate that there is an ability of the buses to move much easier without obstruction from other vehicles during this time period.

7.12 Analysis of the performance of buses on the Elektra Road in Abu Dhabi

Table 7.11 below presents the data to be analysed for the buses travelling on the Elektra Road within Abu Dhabi.

Table 7.11: Summary statistics of bus driving cycle parameters for Elektra Road, Abu Dhabi

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Elektra Road	**6.30.7.30 Am**	323.077	20.502	1819.247	0.179	0.154	0.196	0.467
	11.00-12.00 Am	291.47	20.636	1649.049	0.195	0.164	0.199	0.438

These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest average relative errors. As in previous situations the lowest relative error was presented on the corridor with the readings being taken when the vehicle was travelling in the same direction. However in this situation it has been seen that the lowest relative errors are presented in opposing directions. It has been therefore deemed prudent to select the observations which provide the lowest average relative error so as to provide a comparison of two sets of numbers which were calculated on the same stretch of road operating in the same direction. This has been deemed necessary in this situation as there is an extra bus stop on this route in the outward direction which could possibly lead to a discrepancy in the interpretation of the results being presented.

In this scenario we can see that there is a large variation in the average times taken to complete the corridor, however this can be ignored due to the fact that there is a significant difference in the length of the corridor being examined in the two time periods. Due to the fact that the average speeds are vertically identical we can hypothesise that the overall traffic management methods adopted on this route must be very effective as there is an ability to maintain near uniform average speeds on the route through both peak and off peak traffic flow situations.

As we examine the driving style adopted by the drivers further based on the acceleration and deceleration statistics available we can see that a greater percentage of the journey is spent carrying out these operations in the off peak time period. This indicates to us that the driver has adopted a much more relaxed driving style. This may be based on a number of factors however it may be possible to infer that it is due to an increase in overall traffic volumes on the route during this period and therefore the driver is not capable of accelerating as freely without the risk of obstruction from other vehicles.

As the overall idling time on this route only varies by 0.3% we may infer that there are a near constant number of passengers using this route, as there is not a need for the buses to remain stationary for long periods to allow for the boarding and disembarking of these passengers. The near uniformity of these figures also indicates to us further that there is an extremely efficient traffic management system in place along this route as no variations in the length of time spent queuing at signalised junctions is occurring.

Due to the presence of an increase of 2.9% of the overall journey time spent cruising in the peak traffic time period; we would be lead to infer that there is an overall freer movement of the buses taking place and this may be attributed to an overall reduction in vehicle volumes along the corridor at this time.

7.13 Analysis of the performance of cars on the Airport Road in Abu Dhabi

Table 7.12 presents the data to be analysed for the cars travelling on the Airport Road within Abu Dhabi. These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.12: Summary statistics of car driving cycle parameters for Airport Road, Abu Dhabi

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Airport Road	6.30.7.30 Am	252.64	35.628	2387.998	0.206	0.175	0.143	0.472
	11.00-12.00 Am	188.35	45.609	2364.854	0.203	0.159	0.074	0.56

From the above table we can see that there is a significant difference between the speeds achievable by car users of this route on off peak times as opposed to peak times. We can see that there is an ability to achieve an increase of 9.98 km/hr during the off peak time period which results in a decrease of 64.29 seconds in the average journey time.

From the data available regarding the driving style adopted we can see that the total percentage taken for acceleration and deceleration for the two time periods varies by 1.9%. From this piece of information we can conclude that there is a much more aggressive driving style adopted by the car user during the off peak time. This is clear as a much higher speed is being achieved and then returned to a stationary position taking less time than in the peak time period. The reasoning for this may be safely assumed to be that there are significantly less traffic volumes using the route during the off peak time thus allowing for much more rapid unhindered acceleration and deceleration.

This is also reflected in the data provided for the amount of time spent in the idling and cruising phases for the two time periods. Given that 6.9% more of the journey time is spent idling in the peak time period when compared to the off peak time period, we can assume that there are significantly larger queues developing at the signalised junctions in place along the route. This creation of queues and increase in idling time has a knock on effect in reduction the percentage of the journey which is spent in the cruising phase, and thus increases the overall journey time.

7.14 Analysis of the performance of cars on the Elektra Road in Abu Dhabi

Table 7.13 presents the data to be analysed for the cars travelling on the Elektra Road within Abu Dhabi. These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.13: Summary statistics of car driving cycle parameters for Elektra Road, Abu Dhabi

Route	Time	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Elektra Road	6.30.7.30 Am	209.69	30.552	1762.837	0.187	0.112	0.245	0.452
	11.00-12.00 Am	203.033	33.459	1789.443	0.205	0.116	0.227	0.448

From the above table we can see that there is only a small variance in the average time taken to complete the route in question with only an increase of 2.9km/hr average speed over the course of the corridor.

This would indicate to us that a very small variation in the overall traffic volumes is taking place along this route between the two time periods. Should higher traffic volumes be present in one or other of the time periods, we would expect to see a significant increase in the journey time along with an overall reduction in the average speed, both due to the increased congestion taking place. There may be alterations taking place in the overall traffic volumes but due to these results we can infer that the road network which has been developed here is sufficient to deal with the variations in volume taking place without adversely effecting overall journey time for any of the car users throughout the day.

The increase in the overall percentage of journey time spent in acceleration and deceleration of 2.2% would lead us to believe that there are slightly less traffic volumes in place during the off peak time as there is an allowance for a greater duration of acceleration along with a higher overall average speed occurring.

This is also reflected in the fact that there is 1.8% more of the journey spent in the idling phase in the early morning peak time slot when compared to the afternoon off peak time. However the presence of a slightly higher average cruising percentage of 45.2% in the peak time when compared to the 44.8% of the off peak time would lead us to a contrary belief.
It is clear due to the minimal variation in all of these statistics however that overall there is not a significant change in the overall traffic volumes on this route between the two time periods in question, and if there is a slightly heavier traffic flow it will be occurring in the early morning peak time.

7.15 Analysis of the performance of cars and busses on the Airport Road in Abu Dhabi

Table7.14 below presents the data to be analysed for the buses and cars travelling on the Airport Road within Abu Dhabi. These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.14: Summary statistics of car and bus driving cycle parameters for Airport Road, Abu Dhabi

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Airport Road	6.30.7.30 Am	Bus	544.9	15.61	2331.912	0.186	0.173	0.302	0.335
		Car	252.64	35.628	2387.998	0.206	0.175	0.143	0.472
	11.00-12.00 Am	Bus	437.42	19.127	2248.493	0.187	0.124	0.258	0.427
		Car	188.35	45.609	2364.854	0.203	0.159	0.074	0.56

From the above data we can see that there is a significant difference in journey times and average speeds achieved by the buses and cars on this corridor. This can be attributed however to the fact that this route under examination is a dual carriageway, where there will be minimal disruption to the car users in the instances of the buses stopping.

This is clearly reflected in the data provided for the percentage of time spent in the idling phase. In both situations this percentage is significantly higher for the buses and this may be attributed to their need to make six extra stops along the route than the cars are required to make. The overall acceleration and deceleration percentage times only vary by 7.3% over the entire course of the study on this route which would indicate a very uniform flow of traffic occurring throughout. The main reasoning behind the slightly higher acceleration and deceleration rates of the cars would be down to the fact that they are achieving a significantly higher average speed than the buses which will require a longer time to reach and in turn a longer time to reduce from.

We can also see that the cruising rates for the buses are significantly lower than those of the cars throughout the two time periods, however this is clearly dependant on the idling rates and as there is a requirement of the buses to remain stationary for a greater period of time the cruising rate will in turn decrease.

7.16 Analysis of the performance of cars and busses on the Elektra Road in Abu Dhabi

Table 7.15 below presents the data to be analysed for the buses and cars travelling on the Elektra Road within Abu Dhabi. These statistics have been extracted from Table 6.8 and have been selected as they represent the data collected with the lowest relative errors.

Table 7.15: Summary statistics of car and bus driving cycle parameters for Elektra Road, Abu Dhabi

Route	Time	Mode	Average Time (Sec)	Average Speed (Km/h)	Average Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Elektra Road	6.30.7.30 Am	Bus	323.077	20.502	1819.247	0.179	0.154	0.196	0.467
		Car	209.69	30.552	1762.837	0.187	0.112	0.245	0.452
	11.00-12.00 Am	Bus	291.47	20.636	1649.049	0.195	0.164	0.199	0.438
		Car	203.033	33.459	1789.443	0.205	0.116	0.227	0.448

From the above data we can see that there is a rather large variance in the average time spent on the journey by the different modes of transport. This is clearly associated with the fact that much lower average speeds are being achieved by the buses (on average 11.44 km/hr).

These overall speeds do not represent any significant variation in the overall driving style which is present on the route however. This can be seen in the fact that there is only a 7.2% variation in the overall acceleration and deceleration statistics. Given that there is a requirement of the cars to achieve higher speeds on average this is a minimal variation in overall driving style over the duration of the route being examined.

One surprising statistic is that in total the cars spend on average 7.7% more of the journey time idling when compared to that of the buses. This is an even more interesting figure given that there is a requirement of the buses to service five stops on this inward journey where as there is no requirement of the cars to become stationary at these locations. This information would lead us to believe that the stops must be located near to signalised junctions as this would help to reduce the impact these stops will have on this data field.

The fact that this idling percentage figure for the cars is greater along with the fact that there is a minimal variation in the overall cruising percentages experienced along the route, it can be inferred that the traffic flows on this route are extremely uniform and are most likely being heavily controlled by the signalised junctions present on the route. It is clear that the higher average speeds are being produced by the cars due to their ability to carry out acceleration at a much greater rate than that of the buses and this is the main reason that a reduced journey time is presented.

7.17 Analysis of the performance of vehicles on the traffic calming corridor and the traffic control corridors in Edinburgh

Table 7.16 presents the data to be analysed for the cars travelling on the traffic calming corridors and the traffic control corridors in Edinburgh. These statistics have been extracted from Table 6.6 and Table 6.7.

Table 7.16: Summary statistics of car driving cycle parameters for Corridor 2 (traffic calming corridor) and corridor 4 (control corridor)

Route	Time (Sec)	Average Speed (Km/h)	Length (Meter)	% Acc	% Dec	% Idling	% Cruising
Corridor 2 (Calming Corridor)	97.735	23.87	643.951	0.17375	0.158	0.02	0.64
Corridor 4(Control Corridor)	55.08	29.127	445.923	0.162	0.134	0.024	0.677

From the above data we can see that due to the implementation of a traffic calming system the aims of the installation were achieved. This is evident from this data as there can be seen to be a decrease in the average speed being observed on the corridor by 5.257 km/hr. This is seen to be a significant decrease as it accounts for 5.5% reduction in the speeds being achieved. As these routes are dominated the slow moving vehicles as it is this accounts for a significant proportional reduction and thus increase in overall safety on the route.

The route of this reduction in speed can be determined through the detailed analysis of the driving behaviour of those using the route. In the control it can be seen that a total of 29.6% of the journeys are spent in the acceleration and deceleration phases, whereas in the calming corridor this figure is increased to a total of 33.175% of the journey time. This alteration in percentage journey time represents a significant change in driving style given that overall lower speeds are being achieved. This data along with an apparent reduction in overall percentage time spent in the idling and cruising phases would lead us to believe that the implementation of the calming system has led to much more sporadic and uneven driving styles being adopted while in turn reducing the overall speeds being achieved. This would in turn lead us to infer that the most likely system which has been introduced has been the installation of speed ramps which deem it necessary for vehicles to decelerate on approach but do not require the vehicle to come to a complete stop thus resulting in an overall increase in the deceleration percentage of the vehicle without altering idling time. There is also a requirement to accelerate following the calming measure however the obstructions are often placed at intervals to reduce as much as the maximum speed of the vehicle. Due to this there will be seen an increase in the overall percentage of the journey dedicated to acceleration along with a decrease in cruising times on the given route.

This can be slightly worrying however when examination of this data is carried out and the environmental effect of these driving style alterations is taken into effect. In instances where the duration of time spent in acceleration and deceleration it can be seen that there is an overall increase in the levels of emissions being produced. Due to this it can be assumed that the implementation of this traffic calming system there is an overall increase in the levels of emissions over this route. Due to this it may be deemed prudent for the relevant authorities to attempt in the future to implement systems whereby the percentage acceleration and deceleration times of vehicles are maintained while attempting to increase the cruising percentages being observed while also decreasing the overall average speeds being observed on the route under alteration.

7.18 Summary

From all of the above data we can see that there is a slight reduction in overall journey times for buses and cars in situations where bus lanes are in place. This will indeed lead to overall reduced emissions over the course of the route; however the extent of this reduction will depend greatly on the overall efficiency of the installation of the corridor. As can be seen from the above analysis in certain situations the inclusion of the bus lane results in seemingly insignificant reductions in journey times and in certain situations leads to an increase in overall journey time. We have also seen that where a bus lane is installed this has generally a positive effect on the overall journey times of car users on the routes. This is due to the fact that there is no longer the requirement of the car user to remain stationary behind buses when they are stopped to allow for the collection and alighting of passengers.

The installation of bus lanes can also lead to the situation taking place whereby there is an increase in the overall percentage of the journey time of the vehicles dedicated to acceleration, deceleration and idling. When increases in these activities take place there will be an overall increase in the levels of emissions emanating from the vehicle in question. This is due to the fact that the majority of engines utilised in these vehicles are still quite dated and do not as of yet utilise new technologies to minimise fuel consumption during these times. These vehicles therefore are at a state of optimum fuel consumption during times of cruising where the engine is not set to be running at higher or lower than required consumption levels and thus the overall emission to journey distance ration is at a minimum.

We have also seen that the analysis of driving cycles is a very useful tool in the assessment of the effectiveness of traffic calming measures when they are installed on an existing route. The analysis of driving cycle data taken before and after the installation of the measures allows us to gain an insight to the attitude of the driver using the route during both situation and allows us to determine if the installation has in face resulted in an overall more uniform and controlled driving style being established. This is represented in an overall increase or decrease in the percentage times of the journey which are spent in the various driving phases. Should a traffic calming system be successful it should be hoped to see a slight increase in the overall journey time along a given route along with a decrease in average speed. The percentage phase changes taking place will depend greatly on the type of traffic calming measures utilised. Should it be a reduction of speed limits, an increase in overall cruising time should be seen with a corresponding decrease in acceleration and deceleration percentages taking place. If on the other hand there is some form of traffic light system put in place we should expect to see an increase in idling, deceleration and acceleration taking place with a corresponding decrease in cruising taking place.

CHAPTER 8

FURTHER INVESTIGATION USING REGRESSION ANALYSIS RESULTS

8.1 Introduction

Chapters 5 and 6 presented the results from the runs on the selected traffic corridors. Section 5.2 outlines the main results from the bus lane and the no bus lane corridors. In this chapter further analysis of the results are presented and investigated using techniques of regression analysis.

This analysis requires the identification of some performance indicators in order to effectively compare the performance of the buses and assess the results. The evaluation of the performance is achieved through the calculation of some performance indicators such as percentage time spent in acceleration mode, percentage time spent in deceleration mode, percentage time spent in idling mode and percentage time spent in cruising mode as discussed in Chapters 4 & 5.

Other performance indicators can be identified and have been further investigated in this Section. These indicators include percentage of time spent in acceleration *plus* deceleration modes as this combined mode can represent the worst two driving modes in terms of impacts on delays, congestion and air quality, Barlow et al. (2009). These parameters have been assessed and analysed using regression analysis techniques.

8.2 Regression analysis techniques

In the late 1950's and early 1960's linear regression was the most popular method of prediction in a large number of fields. In transport, regression analysis has been widely used to predict and estimate numbers of trip generations as a function of some relevant factors affecting trip generation. This approach uses trip data collected at one time to determine a functional relationship between, in that case, trip generation (which are known as the 'response' or 'dependent' variable of the function) and the characteristics that exhibit a causal effect on it (which are known as the 'explanatory' or 'independent' variables of the function) utilising the principle of least-squares, i.e. the squared sum of the residuals or deviations from the estimated line is minimised. The linear least-squares model is based on the hypothesis that there exists a linear relationship between some dependent variable and one or more independent variables.

A linear regression analysis predicts the dependent variable Y as a function of some independent variables X by estimating the coefficients θ as:

$$Y = \theta_o + \theta_1 x_1 + \theta_2 x_2 + ... + \theta_n x_n$$

Where

Y = the dependent variable;

X= the independent variables; and

θ= the model coefficients estimated by linear regression. That is, for any given set of observations X_1, X_2, … , X_k there exists a corresponding observation Y which differs from the regression line ($\theta_0 + \theta_1 X_1 + \ldots + \theta_k X_k$) by the amount of ε;

ε= the error terms which are commonly referred to as the disturbance terms of the equation. They arise in practice mainly because the model does not take account of all factors which influence the value of Y; thus the ε values account for the net effect of excluded variables and random deviations.

8.3 The assumptions of the linear regression model

The use of least-squares regression analysis involves a number of important assumptions which mainly include (Douglas and Lewis, 1970):

1. *Distribution of the disturbance terms*. Regarding the disturbance terms it is assumed that their mean and co-variance are zero, their variance is constant and that their distribution is normal. If the variance is not constant then data is said to be heteroscedastic and this may lead to an over-statement of the accuracy of the regression equations.
2. *Collinearity between independent variables*. When two or more variables are inter-correlated (it is known as *multi-collinearity*) it becomes difficult to distinguish their separate effects and sometimes the coefficients of a value or sign may be contrary to intelligent expectation.
3. *Error in variables.* Measurement errors in the independent variables are not allowed for by the model and if present can lead to biased estimates of the equation coefficients.
4. *The shape of the response surface*. It assumes that the dependent variable is a linear function of the independent variables. The independent variables need not be in their original forms and transformations such as the logarithm and reciprocal are sometimes used.

8.4 The tests of the multiple linear regression model

The statistical validity of trip generation analysis derived through linear regression can be assessed by a series of standard statistical tests:

1. *Multiple correlation coefficient (R).* It indicates the degree of association between the independent variables and the dependent variables. Its square is approximately the decimal fraction of the variation in the dependent variable which is accounted for by the independent variables;
2. *'t' test statistic on regression coefficients*. The significance of the regression coefficient of each independent variable in a regression equation is indicated by the '*t*' test statistic. The value of '*t*' is calculated by dividing the regression coefficient by its standard error, and a value of at least 1.96 is necessary for significance to be established at the 95% level.

In addition, the size of the regression constant should be carefully examined - if it is large then the regression set should be used with caution.

Below is an example (Ortúzar and Willumsen, 2001) of a multiple linear regression analysis model to estimate the number of trips per household using number of workers in the household and number of cars (*t*-ratios are given in parentheses):

$$Y = 0.84 + 1.41X_1 + 0.75Z_1 + 3.14Z_2 \qquad R^2 = 0.387$$
$$(3.6) \quad (8.1) \quad (3.2) \quad (3.5)$$

Where

Y is household peak hour trips;

X_1 is the number of workers in the household; and

Z_1 and Z_2 are two dummies for number of cars with Z_1 taking the value 1 for household with one car and 0 in other cases and Z_2 taking the value 1 for households with two or more cars and 0 in other cases (it should be noted that only n-1 dummy variables are needed to represent n intervals); non-car-owning households correspond to the case where both Z_1 and Z_2 are zero.

This model is a good equation in spite of its low R^2. In the model, the intercept 0.84 is not large (i.e. as compared with 1.41 times the number of workers) and the regression coefficients are significantly different from zero with *t*-ratios 8.1, 3.2 and 3.5. The positive signs of the coefficients are correct, i.e. more workers in a household, more household trips and so with the cars owned by the households. In this example, it is clear that there is a non-linear relationship between household car ownership and the number of trips made by a household and in this case, a model with dummy variables is preferable to that with a single ‘number of cars’ linear variable.

8.5 The fits of the linear regression model

There may be a large number of variables to exert a causal effect on trip generation (Douglas and Lewis, 1970). Some of them may be interrelated and measure largely the same effect and others may exhibit only minor influence. The objective of trip end modelling is to provide a reliable forecasting tool. In the process of trip end modelling attention should be given to the following:

1. The explanatory variables must lend themselves to future estimation and be incorporated in a meaningful way with particular regard to the sign and magnitude of their coefficients.
2. If two explanatory variables are highly intercorrelated, it is desirable to override any automatic selection procedure in order to include only the preferred variable, i.e., the one that either has more meaning or may be more easily forecasted.
3. Known or anticipated change in trip-making behaviour should be reflected in the model. For example, models for vehicle trips must reflect the rising level of vehicle ownership.
4. Generally it will be necessary to estimate beyond the range of data used to develop the model in order that future situations are still suitable, and
5. Zonal regression models only explain the variation in trip making behaviour which exists between various traffic zones and can only provide reasonable future estimates if the "between zone" variance sufficiently reflects the true reasons for trip variability. Zones thus should be of homogeneous socio-economic composition and should represent as wide a range of conditions as possible.

As the regression models are to be used to predict future impacts and behaviour, reasonable forecasts can only be expected if the models take account of a sufficient high proportion of the total variation in trip behaviour. Ideally, therefore, the data should be disaggregate and the sample size should be as large as possible to capture most of the effects of the various variables included in the study and to reduce the within parameters variance which is unaccounted for by the model. However, this approach can result in more expensive models in terms of data collection, calibration and operation; and present greater sampling errors which are assumed to be non-existent by the multiple linear regression models. If sampling errors exist in the independent variables, these can produce biased estimates of the regression coefficients. Therefore, care must be taken in decisions related to sample size as well as in terms of interpretation of the results.

8.6 The advantages and disadvantages of regression analysis

The regression analysis method has the following advantages:

1. Regression models are simple;
2. It is relatively easier to include many variables in linear models; and
3. The linear regression models have statistical measures to evaluate the goodness-of-fit, such as *t*-test, the coefficient of determination (R^2) and *F*-test for the complete model.

On the other hand, the regression analysis method has the following disadvantages:

1. The need to assume a linear relationship between dependent variable and independent variables. It is not easy to detect non-linearity because a linear effect may turn out to be non-linear when the presence of other variables is allowed in the model.
2. There is a class of variables in most transport applications, those of a qualitative nature, which usually shows non-linear behaviour (e.g. type of dwelling, occupation of the head of household, age, and sex). In these models, these variables are usually treated as dummy variables where the independent variables under consideration are divided into several discrete intervals and each of them is treated separately in the model. Or some transformation has to be considered, i.e. to transform the variables in order to linearise their effect (e.g. take logarithms, raise to a power). However, selecting the most adequate transformation is not an easy or arbitrary exercise and it takes time and effort.
3. Problems may be encountered in relation to heteroscedasticity and multicollinearity. For zone-based linear regression, the magnitude of the error depends on zone sizes when aggregate variables are used. By using multipliers, this heteroscedasticity can be reduced because the model is made independent of zone size (Ortúzar and Willumsen, 2001).

   For more discussions on regression analysis and example applications in transport predictions see Hobbs, 1979; Koppelman and Pas, 1984; Bruton, 1985; Sheppard, 1986, Hu and Saleh (2005) and Ortúzar and Willumsen (2001).

Sections 8.7 below present the use of regression analysis in the context of modelling impacts of bus lanes on performance of buses on the corridors as well as the results obtained from the regression analysis.

8.7 Modelling the performance of buses on bus lanes using regression analysis

Chapter 6 described the datasets which have been used for the driving cycle development for the different corridors in this study. In this chapter, the data has been further analysed and used to calibrate regression analysis models which represent and describe the impacts of bus lanes and the buses on these corridors. The results are assessed and compared.

It should be reported here that the data set is very limited due to the very small number of corridors investigated. However, the principles of using regression analysis to correlate and investigate relationships of various driving modes and the other factors is appealing. There is a limitation here in terms of the small amount of data available for this task. With larger data set, the results would have been more meaningful.

In this section, a linear regression model for the performance of buses and cars on the "bus lane corridors" in Edinburgh have been developed and investigated. The descriptions of the variables which are used in the linear regression models are given in Table 8.1.

As part of the investigation in this research, some performance indicators have been utilised to derive and assess the driving cycles for different corridors in the transport network. Other indicators can be defined and selected to meet the targets and objectives of any particular study. In our case here, the percentage time spent in acceleration, percentage time spent in deceleration, percentage time spent in idling and percentage time spent in cruising etc. In addition, a new indicator has been used in the regression analysis models to reflect the impacts of the considered traffic demand management measures. This indicator is the percentage of time spent in acceleration *plus* deceleration during the driving cycle, to represent the dependent variable. It is selected because it reflects the time of the driving cycle during which negative impacts on air quality is obtained. In total, nine independent variables have been tested for inclusion in the regression models for both the bus and the car on the bus lane corridors in Edinburgh. These are: peak traffic volume, off peak traffic volume, number of bus stops on the corridor, number of signalised junctions on the corridor, number of pedestrian crossing on the corridor, number of traffic lanes, number of bus routes on the corridor and bus frequency on the corridor as well as type of road. It should also be noted that both of the type of roads and number of lanes variables not included in the analysis because there were no variations in the data to allow this investigation.

In principle, multiple regression analysis could have been used to investigate the different combinations of the independent factors in the models. However, the number of observations in the investigation is very limited as discussed earlier. Therefore, it was not possible to carryout multiple regression analysis because of lack of data. Instead, linear regression analysis was carried out for each individual independent variable. The approach could be further investigated in future research where larger data set can be used. Table 8.1 below shows the list of variables used in this analysis and their definitions.

Table 8.1: Description of variables used in the linear regression model

Variables	Description
TRF_PK	A continuous variable: describes the volume of traffic on the corridor during peak hours.
TRF_OFPK	A continuous variable: describes the volume of traffic on the corridor during off-peak hours.
BUS_STOPS	A continuous variable: describes the number of bus stops on the corridor.
SIGN_JUNS	A continuous variable: describes the number signalised junctions on the corridor.
PED-CROSS	A continuous variable: describes the number pedestrian crossings on the corridor.
TRFK_LANES	A continuous variable: describes the number traffic lanes on the corridor.
BUS_ROUTS	A continuous variable: describes the number of bus routes on the corridor.
BUS_FREQ	A continuous variable: describes the bus frequency on the corridor.

Two sets of linear regression models have been calibrated from this data; one for the bus and one for the car. Table 8.2 show the coefficient estimates and the t-values for each of these models.

8.8 Discussion of the results of the Bus Models

Table 8.2 below, shows the coefficient estimates and the t-values for each of the linear regression models in the case of the bus.

From the table, all the variables have the correct signs and all are statistically significant at the 95% level of significance. The R^2 values of the three models are presented in table 8.2 below. All the R^2 values can be considered reasonably good.

Table 8.2: Linear regression models of % time spent in acceleration plus deceleration and the independent variables

Variables	**Intercept**	**Coefficient**	**R^2**
TRF_PK	0.2302734 (4.101)	2.3E-05 (1.490)	0.379
TRF_OFPK	0.229 (3.745)	2.51E-05 (1.349)	0.290
BUS_STOPS	-0.0047 (-0.0859)	0.018 (5.52)	0.936
SIGN_JUNS	-0.225 (-39.91)	0.086 (91.532)	0.999
PED-CROSS	0.502 (1.359)	-0.0438 (-0.592)	0.481
TRFK_LANES	---	---	---
BUS_ROUTS	0.192 (-4.446)	0.007 (2.746)	0.766
BUS_FREQ	0.186 (4.142)	0.0013 (2.756)	0.767
n	3	3	3

As shown in Table 8.2, the signs of the coefficients for traffic volume during peak hours and during off peak hours are positive as expected. As the number of traffic volume increase, the percentage of time spent on acceleration plus deceleration also increase. However, the t-value of each of these coefficients is not statistically significant at the 95% level of significance.

As the number of bus stops on the corridor increase, also the percentage of time spent on acceleration plus deceleration also increase (positive coefficients of BUS_STOPS in the model) which is logical. As the number of signalised junctions on the corridor increase, the percentage of time spent on acceleration plus deceleration also increases (positive coefficients of SIGN_JUNS in the model) which is also logical. The sign of number of pedestrian crossings (PED-CROSS) on the corridor is negative which indicates that as the number of pedestrian crossings on the corridor increases, the percentage of time spent on acceleration plus deceleration decreases, which is also logical. It should be noted however, that this variable is not statistically significant at the 95% level (t-value is -0.592). The variable representing the number of bus routes on the corridor is statistically significant at the 95% level and has a positive sign in the model, which is logical. Finally, as expected, the variable representing the bus frequency on the corridor is statistically significant at the 95% level and has a positive sign in the model, which is also logical.

To further investigate the results from these models, the relative importance of each variable is obtained. Firstly, the mean value (*m*) of each independent variable is calculated from the survey data (i.e. the average value of each variable). The mean value is then multiplied by the coefficient of the corresponding variable to work out a relative importance value for each variable.

Table 8.3: The relative importance of each variable in the bus model

Variables	**Coefficients**	**Mean Values of Variables (m)**	**Relative Importance of Variables (m * coefficient)**
TRF_PK	2.3E-05	2606.966	6.00E-02
TRF_OFPK	2.51E-05	2411.7	6.05E-02
BUS_STOPS	0.018	16	2.95E-01
SIGN_JUNS	0.086	6	5.15E-01
PED-CROSS	-0.0438	5	-2.19E-01
TRFK_LANES	---	---	---
BUS_ROUTS	0.007	15	9.85E-02
BUS_FREQ	0.0013	83	1.05E-01
n	3	3	

From the models it seems that the number of signalised junctions, the bus frequency and the number of bus stops are the most contributing to the percentage of time spent on acceleration plus deceleration on the corridor. On the other hand it seems that the traffic volume, both peak and off peak have less impact on the percentage of time spent on acceleration plus deceleration.

8.9 Discussion of the results of the car models

Table 8.4 presents the results from the regression analysis of the total time spent in acceleration plus deceleration as a measure of performance of cars on the bus lane corridors and the factors that are tested to have an effect on performance. The Table shows summary results of the regression analysis.

Table 8.4: Linear regression models of % time spent in acceleration plus deceleration and the independent variables for cars

Variables	Intercept	Coefficient	R^2
TRF_PK	0.284 (5.039)	3.43E-05 (2.205)	0.659
TRF_OFPK	0.282 (4.445)	3.78E-05 (1.957)	0.586
BUS_STOPS	-0.033 (-5.711)	0.025 (72.47444)	0.999
SIGN_JUNS	-0.314 (-2.540)	0.115 (5.612)	0.938
PED-CROSS	0.749 (1.659)	-0.075 (-0.842)	-0.170
TRFK_LANES	---	---	---
BUS_ROUTS	0.226 (7.484)	0.002 (5.380)	0.934
BUS_FREQ	0.284 (6.957)	3.43E-05 (5.413)	0.659
n	3	3	

It should be noted that while the type of road and the number of traffic lanes are both relevant, they were not included in the analysis because there was no variations in this variable in the data (only one type of road and number of lanes available as discussed earlier). From the Table, all the variables, all the R^2 values of the calibrated models are reasonable.

As shown in 8.5, the signs of the coefficients for traffic volume during peak hours and during off peak hours are positive as expected. As the traffic volume increase, the percentage of time spent on acceleration plus deceleration also increase and the-values of each of these coefficients is statistically significant at the 95% level of significance.

As the number of bus stops on the corridor increase, also the percentage of time spent on acceleration plus deceleration also increases (positive coefficients of BUS_STOPS in the model) which is logical. As the number of signalised junctions on the corridor increase, the percentage of time spent on acceleration plus deceleration also increase (positive coefficients of SIGN_JUNS in the model) which is also logical. The sign of number of pedestrian crossings (PED-CROSS) on the corridor is negatives which indicates that as the number of pedestrian crossings on the corridor increases, the percentage of time spent on acceleration plus deceleration decreases, which is logical. It should be noted however, that this variable is not statistically significant at the 95% level (t-value is -0.592). The variable representing the number of bus routes on the corridor is statistically significant at the 95% level and has a positive sign in the model, which is logical. Finally, as expected, the variable representing the bus frequency on the corridor is statistically significant at the 95% level and has a positive sign in the model, which is also logical.

To further investigate the results from these models, the relative importance of each variable is obtained. Firstly, the mean value (*m*) of each independent variable is calculated from the survey data (i.e. the average value of each variable). The mean value is then multiplied by the coefficient of the corresponding variable to work out a relative importance value for each variable.

Table 8.5: The relative importance of each variable in the car model

Variables	**Coefficients**	**Mean Values of Variables (m)**	**Relative Importance of Variables (m * coefficient)**
TRF_PK	3.43E-05	2606.966	8.94E-02
TRF_OFPK	3.78E-05	2411.7	9.12E-02
BUS_STOPS	0.025405	16	4.06E-01
SIGN_JUNS	0.114625	6	6.88E-01
PED-CROSS	-0.075	5	-3.75E-01
TRFK_LANES	---	---	---
BUS_ROUTS	0.009315	15	1.40E-01
BUS_FREQ	0.001787	83	1.48E-01
n	3	3	

In all the calibrated models, the estimates of the coefficients are compared. From the models it seems that the number of bus stops, number of signalised junctions, number of pedestrian crossings, and number of bus routes as well as bus frequency are the most contributing to the percentage of time spent on acceleration plus deceleration on the corridor. On the other hand it seems that the traffic volume, both peak and off peak have less impact on the percentage of time spent on acceleration plus deceleration.

8.10 Summary

In this chapter, the results obtained in this study from the analysis of the driving cycle have been further analysed using regression analysis techniques. Regression analysis results show that peak traffic volume, off peak traffic volume, number of bus stops on the corridor, number of signalised junctions on the corridor, number of pedestrian crossings on the corridor, number of bus routes on the corridor and bus frequency on the corridor are all relevant factors which have impacts on the amount of acceleration and decelerations on bus lane corridors. This finding is very important because vehicle emissions increase with the increase in acceleration and deceleration. It should also be noted that both of the type of roads and number of lanes variables where not included in the analysis because there were no variations in the data to allow this investigation. Furthermore, the result provides evidence that the number of signalised junctions, the number of pedestrian crossings and the number of bus routes are the most contributing to the percentage of time spent on acceleration plus deceleration on the corridor, while the traffic volumes on the corridor have less impacts on the percentage of time spent on acceleration plus deceleration. The driving cycle analysis can provide a platform for the investigation and analysis of the performance of traffic and impacts of various transport policies on emissions as well as other environmental issues. Further research and investigations are urgently needed in this area.

CHAPTER 9

CONCLUSIONS

9.1 Introduction

Traffic congestion is nowadays a major problem in almost all of the metropolitan areas of the world. Increasing levels of congestion results in worst predicaments like urban environmental pollution, energy problems and traffic accidents. There has been a move towards utilising TDM measures which aim at reducing car dependency and encouraging the use of other alternative modes such as public transport and/or cycling and walking. In other words, TDM measures are aimed at influencing mode choice, trip length, the frequency of trips and the route taken. However, environmental impacts of such measures have not often been considered as one of the main objectives of such measures. Instead, the main objective has always been the traffic performance and travel time savings. Conventionally, these measures are usually assessed using various analytical modelling and analysis techniques (for example travel demand forecasting, simulation modelling etc.). A major limitation of much of these approaches is that the assessments are usually calculated based on average speed patterns and not on real-world driving conditions, which are much more detailed and reflect the actual performance of the traffic and the system. Therefore, the conventional techniques do not embrace actual driving behaviour in any particular urban area. Driving cycle analysis can be used to obtain more real data to assess the impacts of TDM measures on congestion, delays and travel time. Measurement of instantaneous speed, acceleration, deceleration, and distance travelled and route tracking data can be used to develop the driving cycle for each of the modes. It should be emphasised here that, most of the work on development of driving cycles has been carried out with emission monitoring and measurement, in mind. Therefore, there is no previous literature was found in this area. This is therefore one of the novel areas of this research.

The motivation behind this research is to investigate effects of different TDM measures that are already applied to improve the network performance. It is important to explicitly assess these transport policy measures with a very detailed analysis of driving cycles in order to monitor the impacts of policies on network performance and on emissions as well. These understandings will benefit government agencies and policy makers in their planning and appraisals. It will also benefit public transport providers to improve their service in attracting and retaining their customers.

The main goal of this research therefore has been to investigate impacts of travel demand management measures using driving cycle characteristics. Furthermore, this study has also developed real world driving cycles for traffic corridors in Abu Dhabi and investigated their impacts on emissions. The specific objectives of this research are:

1. ***To investigate and analyse in more details impacts of bus lanes on traffic using the analysis of the driving cycles of buses on a number of corridors.***
2. ***To investigate and analyse the driving cycles on a number of traffic calming corridors.***
3. ***To investigate the driving cycle on traffic corridors in a developing country.***
4. ***To analyse and compare the obtained driving cycle results and draw conclusions on the possible impacts of various travel demand management policies.***
5. ***To attempt using regression analysis techniques to establish mathematical relationships between speeds and the other performance parameters discussed above.***

9.2 Summary of Achievements

9.2.1 Meeting the objectives of the research

The main aim of this research has been to investigate the potential application of the driving cycle techniques to assess transport policies and the detailed impacts on the built environment in Edinburgh and in Abu Dhabi. In order to achieve this aim a number of objectives have been defined as discussed below.

The first objective of this research has been to investigate and analyse in more details impacts of bus lanes on traffic using the analysis of the driving cycles of buses on a number of corridors.

Bus lanes have been claimed to improve traffic performance, improve bus reliability and reduce delays. However, most of research in this area relies on investigating performance of the buses in terms of speed and travel times only. Other criteria of bus performance such as acceleration, deceleration, idling and cruising are not usually included. In order to assess the more in depth impacts of bus lanes on traffic, the driving cycle of the selected three traffic corridors in Edinburgh have been identified and data has been collected using GPS equipment to carry out the investigations. The results obtained have been presented in chapters Five and Six.

From the results, it can be seen that in all instances, on the bus lane corridor, there is a significant reduction in journey times when using cars as opposed to buses as the method of transportation. It can also be seen that higher average speeds were achieved at all times by cars than buses, on the bus lane corridors. It was also revealed that when the bus lane is in operation the cars are capable of achieving a rate of 52% of the journey at cruising rates in comparison to the 39.6% achieved by the buses. This along with increased idling times for the buses both contribute to the lower average speed and thus higher journey time of the buses.

Further analysis of the results show that in terms of idling times, it is also seen that the bus spends much more higher time idling than the cars during both peak and off peak times (135% & 72.2% higher idling times) respectively. In terms of cruising times, it is also seen that the bus spends much less time cruising than the cars during both peak and off peak times (31.3% & 13.1% higher cruising times) respectively. In the scenario of the before the bus lane operation, that is between 6.30 and 7.30 am, the bus performance relative to that of the cars is also similar. That is the idling times for the bus is 165% higher than that of the cars while the cruising times are similar.

We can also see that once the bus lane is no longer in use there is a fall off in the overall journey times of all vehicles on the route. This may be due to overall higher traffic and pedestrian rates, however this is unlikely. The lack of a bus lane could be seen as the likely factor for these delays with vehicles being forced to interact with each other to a greater extent when the bus lane is in effect. This lack of a bus lane has an effect on the traffic stream as a whole. However, there may be grounds also to claim that the presence of the bus lanes do not necessarily brings advantages to the buses. This might be because of the fact that buses are forced to queue up in the bus lane and are not free to overtake other traffic and leave the queue which might results in higher idling times for buses than they are for cars for example. Further research in this direction is certainly needed.

Investigating the data that present the cars and busses travelling on the A702 (no bus lane road) within Edinburgh city, we can see that there is a significant reduction in journey time along with an increase in average speed for car users along this corridor as a whole. Once more a question is raised regarding the actual benefits of bus lanes since the performance of the cars is way better than those of the buses.

The data which present the busses travelling on the A7and A702 roads within Edinburgh city has also been investigated. From this data we can see that on the A7 during the times when the bus lane is in effect there is in fact more of a restriction in the amount of time spent cruising by the busses. This time is not however directly transferred to the idling time but instead is associated with the acceleration and deceleration phases of the journey. This would indicated that while there is an overall reduction in the amount of time spent at a constant speed there is in effect an increase in the overall time spent in motion. When this is compared to the A702 for the same time period we can see that there is a greater percentage of the overall journey spent in the idling phase. However as this represents only a 0.6% difference it is hard to verify the reasons for this change in behaviour. This could be down to a slightly higher number of passengers availing of the bus service along this route at this time. From this we can see that there is no clear advantage to the implementation of the bus lane to help to speed up the flow of the busses on these routes. It can be envisaged if a bus lane was to be implemented on the A702 there would also be little or no benefit to the busses efficiency, however the benefits that it may provide to the other road users is also a vital benefit.

From the data presented in table 7.9, we can see that due to the implementation of the bus corridor in the peak time on the A7 there is an increase in the overall time spent in motion by the cars travelling on this route when compared to that of the off peak time. This is most likely due to the presence of the bus lane at this time removing the busses from the main thoroughfare and providing them with their own lane and thus eliminating any possible conflicts between the two transport modes.

It can also be seen that when a comparison is made between the two different routes at the same time periods that there is a significantly higher percentage of the cars journey spent in the idle phase on the A702. This may be attributed also to the fact that there is no bus lane provided on this route and thus there is a reduced opportunity for the cars to overtake these busses when they are required to stop to pick up passengers. It can also be seen however that the overall percentage of time spent in the cruising phase on the A702 is higher than on the A7 with lower total acceleration and deceleration times present also. This would lead us to believe that the aim and the implementation of bus lanes should be revisited in order for this policy to meet its targets.

Therefore, while there are some evidence to support the claims that bus lanes may improve traffic performance, there may be grounds also to claim that the presence of the bus lanes do not necessarily bring advantages to the buses. This might be because of the fact that buses are forced to queue up in the bus lane and are not free to overtake other traffic and leave the queue which might results in higher idling times for buses than they are for cars for example. Further research in this direction is certainly needed.

The second objective of this research has been to investigate and analyse the driving cycles on a number of traffic calming corridors.

In order to assess the performance of traffic over traffic calming corridors, which are claimed to be improving the impacts of traffic, the performance of traffic on a number of traffic calming corridors have been assessed, analysed and investigated. The descriptions of the traffic calming corridors are presented in Chapter Three. The developments of driving cycles of these corridors are discussed in Chapter Six and the comparisons and discussions of the results are presented in Chapter Seven.

The implementation of traffic calming systems can result in a decrease in the average speed being observed on the corridor by 5.257 km/hr. This is seen to be a significant decrease as it accounts for 5.5% reduction in the speeds being achieved. The reason for this reduction in speed can be determined through the detailed analysis of the driving behaviour of those using the route. In the case of the control corridor it can be seen that a total of 29.6% of the journeys are spent in the acceleration and deceleration phases, whereas in the calming corridor this figure is increased to a total of 33.175% of the journey time. This alteration in percentage journey time represents a significant change in driving style given that overall lower speeds are being achieved. This data along with an apparent reduction in overall percentage time spent in the idling and cruising phases would lead us to believe that the implementation of the calming system has led to much more sporadic and uneven driving styles being adopted while in turn reducing the overall speeds being achieved. This would in turn lead us to infer that the most likely system which has been introduced has been the installation of speed ramps which deem it necessary for vehicles to decelerate on approach but do not require the vehicle to come to a complete stop thus resulting in an overall increase in the deceleration percentage of the vehicle without altering idling time. There is also a requirement to accelerate following the calming measure however the obstructions are often placed at intervals to reduce as much as the maximum speed of the vehicle. Due to this there will be seen an increase in the overall percentage of the journey dedicated to acceleration along with a decrease in cruising times on the given route.

This can be slightly worrying however when examination of this data is carried out and the environmental effect of these driving style alterations is taken into effect. In instances where the duration of time spent in acceleration and deceleration increase it can be seen that there is an overall increase in the levels of emissions being produced. Due to this it can be assumed that the implementation of this traffic calming system there is an overall increase in the levels of emissions over this route. Due to this it may be deemed prudent for the relevant authorities to attempt in the future to implement systems whereby the percentage acceleration and deceleration times of vehicles are maintained while attempting to increase the cruising percentages being observed while also decreasing the overall average speeds being observed on the route under alteration.

The third objective of this research has been to investigate the driving cycle on traffic corridors in a developing country.

Driving cycle techniques are mainly used in the western world. This is because the main applications of driving cycle have been in the area of emission modelling. Since environmental impacts and emission analysis are not the most important issues on the national agendas in developing countries, these techniques therefore have been less known in such areas. These results are presented in Chapter Five.

In order to achieve this, data was collected from two traffic corridors in the city of Abu Dhabi (UAE) and analysed. Driving cycle for cars and for buses have been developed and analysed. These results are presented in Chapter Five. The data to be analysed is for the buses and cars travelling on the Elektra Road within Abu Dhabi. From the above data we can see that there is a rather large variance in the average time spent on the journey by the different modes of transport. This is clearly associated with the fact that much lower average speeds are being achieved by the buses (on average 11.44 km/hr).

These overall speeds do not represent any significant variation in the overall driving style which is present on the route however. This can be seen in the fact that there is only a 7.2% variation in the overall acceleration and deceleration statistics. Given that there is a requirement of the cars to achieve higher speeds on average this is a minimal variation in overall driving style over the duration of the route being examined.

One surprising statistic is that in total the cars spend on average 7.7% more of the journey time idling when compared to that of the buses. This is an even more interesting figure given that there is a requirement of the buses to service five stops on this inward journey where as there is no requirement of the cars to become stationary at these locations. This information would lead us to believe that the stops must be located near to signalised junctions as this would help to reduce the impact these stops will have on this data field. These types of findings are helpful for the practitioners and traffic engineers in order to help them to efficiently design the transport system in order to optimise its performance.

The fact that this idling percentage figure for the cars is greater along with the fact that there is a minimal variation in the overall cruising percentages experienced along the route, it can be inferred that the traffic flows on this route are extremely uniform and are most likely being heavily controlled by the signalised junctions present on the route. It is clear that the higher average speeds are being produced by the cars due to their ability to carry out acceleration at a much greater rate than that of the buses and this is the main reason that a reduced journey time is presented.

The fourth objective of this research has been to analyse and compare the obtained driving cycle results and draw conclusions on the possible impacts of various travel demand management policies.

Chapter Seven presented a comprehensive comparative analysis for the results obtained in this research regarding driving cycles. The analysis include comparisons of performance of each of the vehicle types (that is the bus and the private car) during peak and off peak traffic hours, a comparison of the buses and cars on each corridor and a comparison of each of the bus and the car on each corridor type (that is the bus lane, no bus lane and bus only corridors). These types of comparisons and analysis are very useful for the understanding of the performance of traffic and the implications of various transport policies which can be implemented to improve traffic.

Moreover, driving cycles are useful for not only developed countries but also for the developing countries. Furthermore, developing countries being short of resources in turn require extensive analysis of big projects that suit their local conditions. This study found that driving cycle can provide useful information about the applicability of different traffic improvement measures. The results show that the bus lanes could be implemented in Abu Dhabi in order to attract more people to public transport and distribute the demand between different modes as well as to improve congestion and reduce delays. It is important however, to use the right approach for the investigation and implementation of such policies. For example, driving cycle analysis is an appropriate tool to be used for such investigations.

The final objective of this research therefore, is to attempt using regression analysis techniques to establish mathematical relationships between speeds and the other performance parameters discussed above.

In chapter eight, data collected in this research has been further analysed and used to calibrate regression analysis models which represent and describe the impacts of bus lanes and the buses on these corridors. The results are assessed and compared. Although the available data set is very limited due to the very small number of corridors investigated, the principles of using regression analysis to correlate and investigate relationships of various driving modes and the other factors is appealing. Further research should be directed to further investigate this type of analysis.

A linear regression model for the performance of buses and cars on the “bus lane corridors” in Edinburgh have been developed and investigated. Some performance indicators have been utilised to derive and assess the driving cycles for different corridors in the transport network. Other indicators can be defined and selected to meet the targets and objectives of any particular study. That is the percentage time spent in acceleration, percentage time spent in deceleration, percentage time spent in idling and percentage time spent in cruising etc. In addition, a new indicator has been used in the regression analysis models to reflect the impacts of the considered traffic demand management measures. This indicator is the percentage of time spent in acceleration *plus* deceleration during the driving cycle, to represent the dependent variable. It is selected because it reflects the time of the driving cycle during which negative impacts on air quality is obtained. Nine independent variables have been tested for inclusion in the regression models for both the bus and the car on the bus lane corridors in Edinburgh, including peak traffic volume, off peak traffic volume, number of bus stops on the corridor, number of signalised junctions on the corridor, number of pedestrian crossing on the corridor, number of traffic lanes, number of bus routes on the corridor and bus frequency on the corridor as well as type of road. As discussed, other variables could have been used subject to the case under investigation.

In all the calibrated models, the estimates of the coefficients are compared and analysed and seem reasonable. From the models it seems that the number of bus stops, number of signalised junctions, number of pedestrian crossings, and number of bus routes as well as bus frequency are the most contributing to the percentage of time spent on acceleration plus deceleration on the corridor. On the other hand it seems that the traffic volume, both peak and off peak have less impact on the percentage of time spent on acceleration plus deceleration. The driving cycle analysis can provide a platform for the investigation and analysis of the performance of traffic and impacts of various transport policies on emissions as well as other environmental issues. Further research and investigations are surely needed in this area.

Last but not least, it should be mentioned here that the added value of this research to future policy making in Abu Dhabi in for example the introduction and the investigations of bus lanes and other bus measures. It was also be helpful for the researcher to learn and observe the differences in practices, including data collections and problems associated during the contrasting case studies of Edinburgh and Abu Dhabi.

9.3 Recommendations for further research

Travel demand management measures have been used to manage the demand for travel for more than three decades or so, mainly in the Western World. The main objectives have been essentially used to reduce negative impacts of traffic and congestion. Improving environmental impacts, accidents reduction as well as impacts of other externalities have always been mentioned as by products of achieving congestion reduction. On the other hand, driving cycle techniques and analysis have been used *mainly* to predict and model traffic emissions for cars as well as other modes of travel. Driving cycle analysis can be used as a very useful tool to assess impacts of transport policies on environmental and other external issues. In this research, the principles of driving cycle analysis have been used to assess and investigate the impacts of bus lanes and traffic calming measures on traffic performance. This is a very important development in the investigation and analysis of travel demand management policies. It should be added here however, that the choice of TDM measures for case studies was influenced by the Edinburgh context. And therefore, many other TDM measures can be considered if suitable case studies were available.

The number of traffic corridors investigated, the time periods, the type of vehicles tested and type of drivers however, have been limited by the time and survey costs constraints. Further investigations of impacts of transport policies on the performance of traffic using driving cycles analysis is strongly recommended.

Moreover, driving cycle analysis has been mainly used in the western world's cities and in the relatively more advanced developing countries. This is because the main applications of driving cycle have been in the area of emission modelling. Since environmental impacts and emission analysis are not the most important issues on the national agendas in developing countries, these techniques therefore have been less recognised in these countries. These results are presented in Chapter Five. One of the objectives of this research has been to investigate the driving cycle on traffic corridors in a developing country. In order to achieve this, data was collected from two traffic corridors in the city of Abu Dhabi (UAE) and analysed. Driving cycles for cars and for buses have been developed and analysed.

The study has been limited however to one city in the UAE, and to two corridors because of time and money constraints. Similar studies should be implemented however in other cities in the UAE and other developing countries and results should be compared. In addition, further investigations of this approach in Abu Dhabi will provide critical evaluation before the implementation of any TDM measure. Moreover, as this is a novel application in a bus context, it should be acknowledged that technology for research is advancing constantly and that future research could, for example, also include video data.

Furthermore, the driving cycle analysis and investigations have always been based on the analysis of speed-time diagrams and investigations of average values of speeds, acceleration, and deceleration, cruising and idling. There are no further statistical or analytical techniques such as regression analysis for example to attempt to analyse and investigate mathematical models for the relationships between those parameters.

In this research, the final objective has been to attempt using regression analysis techniques to establish mathematical relationships between speeds and the other performance parameters discussed above. This analysis can provide a platform for the investigation and analysis of the performance of traffic and impacts of various transport policies on emissions as well as other environmental issues. Further research and investigations are urgently needed in this area to investigate larger numbers of independent variables, larger sample size, investigate possibility of multiple linear regression and investigate further modelling and statistical techniques. Finally, further investigations and analysis of driving cycle is urgently recommended in a number of research directions. Combined GIS and GPS data could also enhance the development in this research.

A final note on the future directions which could reflect on the possible extensions to the applications of driving cycle analysis to include vehicle types and other vehicle characteristics in the analysis and the exploring of the sensitivity of different traffic calming measures and interaction with practitioners are also very relevant.

LIST OF REFERENCES

ADB (2010) *Travel Demand Management & Road User Charges* [online] available from http://www.adb.org/projects/PRCRoadSafety/tdm.asp [Accessed 6th January 2010]

Aerde, M. V. and Yagar, S. (1983) Volume Effects on Speeds of 2-Lane Highways In Ontario. *Transportation Research Part A*, 17A, 301-313.

Ahn, K., Rakha, H., (2009) A field evaluation case study of the environmental and energy impacts of traffic calming T*ransportation Research Part D: Transport and Environment*, Volume 14, Issue 6, pp. 411-424

Al-Zubaidi, M. S. and Sabie, K. K. Sustainable Transportation in United Arab Emirates *GBER* Vol 5 No. 2 pp 63 – 73, n.d

Andre, M. (1996) Driving cycle's development: characterisation of the methods. *SAE paper*. 961112.

Andre, M. (2004) The ARTEMIS European driving cycles for measuring car pollutant emissions. *Science of the Total Environment*. 334 and 335 pp. 73–84.

Andre, M., Hickman, J., Hassel, D., and Joumard, R. (Ed.), (1995) Driving cycles for emission measurements under European conditions. In*: Global Emission Experiences: Processes, Measurements and Substrates*. Society of Automotive Engineers (SAE), Warrendale, SP-1094. pp. 193–205.

Andre, M., Joumard, R., Vidon, R., Tassel, P., and Perret, P. (2006) Real-world European driving cycles, for measuring pollutant emissions from high- and low-powered cars. *Atmospheric Environment*. 40, pp. 5944–5953.

Barlow, T.J., Latham, S., McCrae, I.S & Boulter, P.G (2009): A reference book of driving cycles for use in the measurement of road vehicle emissions PPR354: *TRL (Transport research Laboratory)*, England.

Basso, L. J., Guevara, C. A., Gschwender, A., Fuster M. (2011) Congestion pricing, transit subsidies and dedicated bus lanes: Efficient and practical solutions to congestion. *Original Research Article Transport Policy*, Volume 18, Issue 5, pp. 676-684

Bates, R.R., & Kennedy, D. (1988): Air Pollution, the automobile and public health: *National Academies,* USA.

Beevers, S.D. & Carslaw, D.C (2004): The impact of congestion charging on vehicle emissions in London *Atmospheric Environment 39 (2005) 1–5*

Bener, A., Breger, A. and Al-Falasi, A. S. (1994) Risk taking Behaviour in road traffic accidents *J traffic Med.* Vol 22 pp 143 – 148

Bexley, (2002) [online] *London Bus Initiative*, *Enforcement of Bus Lanes, Waiting and Loading Restrictions.* Available from http://democracy.bexley.gov.uk/Data/Environment,%20Transport%20&%20Regeneration%20Portfolio/20020927/Agenda/SubIndex$27.09.02%20London%20Bus%20Initiative%20-%20Bus%20Lane%20Enforcement%20etc..htm [Accessed 23rd March 2012].

Booth et al,. (2002) *Measurements of vehicular driving cycle within the city of Edinburgh* [online] available from http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH8-42HFR41-4&_user=10&_coverDate=05/31/2001&_rdoc=1&_fmt=high&_orig=browse&_sort=d&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=869789882efe8b68e90a95223280829a [Accessed 5th January 2010]

Booth, A.E., Munner, T., and Kirby, H.R. (2001) The measurement of vehicular driving cycle within city of Edinburgh. *Transportation Research Part D*. 6, pp. 209–220.

Boulter, B. G., Latham, S., Ainge, M., (1999) Driving cycles for measuring passenger car emissions on roads with traffic calming measures. S*cience of The Total Environment,* Volume 235, Issues 1-3, pp. 77-89

Brake, J. & Nelson, J.D. (2007) A case study of flexible solutions to transport demand in a deregulated environment. *Journal of Transport Geography*, Volume 15, Issue 4, Pages 262–273.

Bruton, M.J. (1985) *Introduction to Transportation Planning*. Hutchinson, London.

Chatterjee, A. & Venigalla, M.M (nd.) [online] *Travel Demand Forecasting For Urban Transportation Planning.* Available from http://mason.gmu.edu/~mvenigal/CEIE462562/Book_Chapter_by_Chatterjee_and_Venigalla.pdf. [Accessed 25th March 2012].

Chen, K.S., Wang, W.C., Chen, H.M., Lin, C.F., Hsu, H.C., Kao J.H., and Hu, M.T. (2003) Motorcycle emissions and fuel consumption in urban and rural driving conditions. *Science of the Total Environment*. 312, pp. 113–122.

Cloke J, (1999) *Planning, Safety, General Design Considerations* [online] available from http://www.standardsforhighways.co.uk/dmrb/vol2/section2/bd7899.pdf [Accessed 13th February 2010]

Cloke, J., Harris, G., Latham, S., Quimby, A., Smith, L. and Baugham, C. (1999) Reducing the environmental impact of driving: a review of training and in-vehicle technologies. *TRL (Transport Research Laboratory) Report*. 384, p. 31. Crowthorne.

Collins English Dictionary and Thesaurus (2006) bus lane [online] available from http://dictionary.reverso.net/english-cobuild/bus%20lane [Accessed 20th January 2010]

Corrales, M., Grant, M. & Chan, E (2000) *Indicators of the Environmental Impacts of Transportation: highway, rail, aviation and marine transport*. DIANE publishing, USA.

Daham, B., Andrews, G.E., Li, h., Partridge, M., (2005). Quantifying the Effects of Traffic Calming on Emissions Using On-road Measurements, *SAE International* 2005-01-1620.

Dahlgren, J., (1998) High occupancy vehicle lanes: Not always more effective than general purpose lanes. *Original Research Article Transportation Research Part A*: Policy and Practice, Volume 32, Issue 2, pp. 99-114

Deng, T., & Nelson, J.D.. *Recent Developments in Bus Rapid Transit: A Review of the Literature.* Transport Reviews, 31(1), 69-96. 2011.

Defra (Department for Environment, Food and Rural Affairs) London. (2008) [online] available from http://archive.defra.gov.uk/environment/quality/air/airquality/publications/smog/winter-smog-summer-smog.pdf [Accessed 15th January 2012]

DfT (Department for Transport, UK) (2010) [online] *Case Study London Congestion Charging*, Available from http://www.dft.gov.uk/itstoolkit/CaseStudies/london-congestion-charging.htm [Accessed 25th March 2012]

DfT (Department for Transport, UK) (2011) [online] Measuring and Reporting Greenhouse Gas Emissions. *A Department for Transport Guide to Work-Related Travel*: Department for Transport, England. Available from http://assets.dft.gov.uk/publications/pgr-sustainable-greenhousegasemissions-pdf/greenhousegasemissions.pdf [Accessed 25th March 2012]

DfT (Department for Transport, UK) (2008) [online] Roads- Delivering choice and reliability: Department of Transport, England. Available from http://webarchive.nationalarchives.gov.uk/+/http:/www.dft.gov.uk/pgr/roads/introtoroads/roadcongestion/roadscommandpaper1.pdf [Accessed 25th March 2012]

DfT (Department for Transport, UK) (2012) [online] *Transport Statistics*. Available from http://www.dft.gov.uk/statistics/releases/tsgb-2011-vehicles/> [Accessed 24th March 2012].

DfT (Department for Transport, UK) (2010) [online] *Sustainable Transport*. Available from http://www.dft.gov.uk/about/strategy/whitepapers/previous/anewdealfortransportbetterfo5695?page=5 [Accessed 10th January 2010]

DfT (Department for Transport, UK) (2010b) [online] *Bus Priority* .Available from http://www.dft.gov.uk/pgr/regional/buses/bpf/buspriorithewayahead12/rioritythewayaheadpdfversion.pdf [10th January 2010]

Donna C., Nelson, J.D., (2000) Intelligent Transportation Primer. *Institute of Transportation Engineers*, Washington, D.C. pp. 10-1, 2000.

Dowling, R.G (2005): Predicting air quality effects of traffic flow improvements : final report and users guide Report 535: *Transportation Research Board*, USA.

El Mallakh, R. (1981) *The economic development of the United Arab Emirates*. London, Taylor & Francis, 1981

Elvic R. (2001) Area-wide urban traffic calming schemes: a meta-analysis of safety effects. *Accident Analysis & Prevention*, Volume 33, Issue 3, pp. 327-336

Ergeneman, M., Sorusbay, C., and Go Ktan, A. (1997) Development of a driving cycle for the prediction of pollutant emission and fuel consumption. *International Journal of Vehicle Design*. 18, pp. 391–399

Ericsson, E. (2000) Variability in urban driving patterns. *Transportation, Research, Part D: Transportation and Environment*, 5(5), 337-354.

Esteves-Booth, A, Muneer, Tariq, Kirby, Howard and Kubie, Jorge (2001) The measurement of vehicular driving cycle within the city of Edinburgh. *Transportation Research Part D Transport and Environment*, 6 (3). pp. 209-220.

European Transport Conference, (1999) [online] *Comparative evaluation of Greenways and bus lanes*. Available from http://www.etcproceedings.org/paper/comparative-evaluation-ofgreenways-and-bus-priority-lanes [Accessed 23rd March 2012].

European Environment Agency, (2012) [online] *Sources of Air Pollution* .Available from http://www.eea.europa.eu/publications/2599XXX/page010.html> [Accessed 25th March 2012].

Faiz, A., Weaver, C.S & Walsh, M.P (1996): Air Pollution from motor vehicles: standards and technologies for controlling emissions: *World Bank Publications*, USA.

Gakenheimer, R. (1999). Urban mobility in the developing world. *Transportation Research Part A*, Vol 33, 671-689

Galante F, Mauriello F., Montella A., Pernetti, M., Antonio D’Ambrosio M., (2010) Traffic calming along rural highways crossing small urban communities: Driving simulator experiment. *Accident Analysis & Prevention*, Volume 42, Issue 6, pp. 1585-1594

Galin, D., (1981) Speed on Two-Lane Rural Roads. A Multiple Regression Analysis. *Traffic Engineering + Control*, 22(8/9), 453 – 463.

Gandhi, K.K., Zvonow, V.A. and Harbans, S. (1983) Development of a driving cycle for fuel economy in developing country. *Transportation Research.* 17-A (1), pp. 1-11.

Garling et al., (2002) Travel Demand Management Targeting Reduced Private Car Use: Effectiveness, Public Acceptability and Political Feasibility, *Journal of social issues* vol63, no.1, 2007, pp 139-153

Gomez-Ibanez, J.A.and Small, K.A., (1994): National Cooperative Highway Research Progam. Road NCHRP Synthesis 210 .Pricing for congestion management: a survey of international practice: *Transportation Research Board*, USA.

Greater London Authority, (2001) [online] *Improving London's Bus Services. An assembly investigation into the quality and performance of London's Buses*. Available from http://legacy.london.gov.uk/assembly/reports/transport/improving_bus_services.pdf [Accessed 23rd March 2012].

Green, K. (1995) Defending Automobility: *A Critical Examination of the Environmental and Social Costs of Auto UseReason Foundation* (1995)

Hargreaves, A.J (1997) *Public Preferences for traffic calming: an investigation using multi-criteria procedures*. University of Leeds, England.

Harvey, T. (nd.) A Review of current traffic calming techniques: *Institute of Transport Studies*, University of Leeds, England. Available from http://www.its.leeds.ac.uk/projects/primavera/p_calming.html [Accessed 25th March 2012]

Hensher, D. A. and Button, K. J. *Handbook of transport and the Environment*. Oxford; Emerald Group Publishing, 2003

Hester, R. E. and Harrison, R. M. *Transport and the environment*. Cambridge; Royal Society of Chemistry, 2004

Hobbs, F.D. (1979) *Traffic Planning and Engineering*. Pergamon Press, London.

Hodges, J. (2007) Keeping London Moving. Bus Priority in London. *European Transport Conference, TfL (Transport For London)*, England.

Höglund, P.G., Niittymäki, J., (1999) Estimating Vehicle Emissions and Air Pollution related to Driving Patterns and Traffic Calming. In: *Urban Transport Systems Conference Proceedings*, Lund.

Holmen, B. A. and D. A. Niemeier. (1997) Characterizing the effects of driver variability on real-world vehicle emissions. *Transportation Research, Part D: Transportation and Environment*, 3(2), 117-128.

http://www.tfl.gov.uk/assets/downloads/FourthAnnualReportFinal.pdf [Accessed 24th March 2012]

Hu, S. and Saleh, W. (2005) Impacts of congestion charging on shopping trips in Edinburgh. *Transport Policy* 12, 443-450.

Hung, W., Tam, K., Lee, C., Chan, L.Y., and Cheung, C.S. (2005) Comparison of driving characteristics in cities of Pearl River Delta, China. *Atmospheric Environment*. 39, pp. 615–625.

Hung, W.T., Tong, H.Y., Lee, C.P., (2007) Development of a practical driving cycle construction methodology. A case study in Hong Kong. *Transportation Research D* 12, 115–128.

Hyden, C., Odelid, K., Varhelyi, A., (1995) The effects of general speed calming in built-up areas. *Results of a large scale experiment in Vaxjo*. University of Lund.

Int Panis, L., Beckx, C. & Broekx, S. (2006) Impact of 30 km/h zone introduction on vehicle exhaust emissions in Urban Areas. *Association for European Transport and contributors.*

International Transport Forum (ITF) OECD (2010) ITF Round Tables Implementing Congestion Charges. *Transport Research Centre OECD Publishing*, France.

Ismail, M. 'New Measures to deter speeding on Abu Dhabi city limits' (2011). *The National* .Available from http://www.thenational.ae/news/uae-news/new-measures-to-deter-speeding-on-abu-dhabi-city-limits, [Accessed 23th January 2011]

Ison, S. & Rye, T.(Editors) (2008) *The implementation and effectiveness of transport demand management measures, an international perspective*. Ashgate Publishing, England.

Ison, S. (2004) *Road User Charging, issues and policies*. Ashgate Publishing, England.

Jens Schade (2002) Public and Political Acceptability as Criteria for Implementation Paths, Urban and Interurban Road [online] available from http://www.its.leeds.ac.uk/projects/mcicam/handouts/3rdsemsep2002/mcicam_helsinki_schade.pdf [Accessed 11th February 2010]

Jensen, K. H.; Kildebogaard, J. Strategi C-et nyt begreb i vejplanlzgningen. Vejdirektoratet-Vejdatalaboratoriets rapport 28; 1981.

Joumard, R., Andre, JM., Rapone,M., Zallinger,M., Kljun, N., Andre,M., Samaras, Z., Roujol,S., Laurikko, J., Weilenmann, M., Markewitz, K., Geivanidia, S., Ajtay, D. & Paturel, L.(2007): Report n°LTE 0523 Emission Factor Modelling and Database for light vehicles: INRETS France. Available from http://www.inrets.fr/ur/lte/publi-autresactions/fichesresultats/ficheartemis/road3/database32/Artemis_deliverable_3_LTE0523_adobe7.pdf [Accessed 12th March 2011]

Joumard, R., Andre, M., Vidon, R., and Tassel, P. (2003) Characterizing real unit emissions for light duty goods vehicles. *Atmospheric Environment.* 37, pp. 5217–5225.

Jourquin, B., Rietveld, P., & Westin, K.(2006) *Towards better performing transport networks* . Taylor & Francis, England.

Kamble, S.H., Mathew, T.V. and Sharma, G.K. (2009) Development of real world driving cycle: Case study of Pune, India. *Transportation Research-D.* 14(2), pp. 132-140.

Kent, J.H., Allen, G.H., and Rule, G. (1978) A driving cycle for Sydney. *Transportation Research.* 12 (3), pp. 147–152.

Kilpelaninen, M. and H. Summala. (2004) Effects of weather forecasts on driver behaviour. *3rd International Conference on Traffic and Transport Psychology*, Finland.

King, N. & Bod, C. (1997) Making Bus Priority Work, whole route control. *ETC Conference 1997*, England.

Koppelman, F. S. and Pas, E. I. (1984). Estimation of disaggregate regression models of person trip generation with multi-day data. In J. Volmuller and R. Hamerslag (eds), *Proceedings of the Ninth International Symposium on Transportation and Traffic Theory*. VNU Science Press, Utrecht.

Koshy R. Z., and Thamizh Arasan, V. (2005) Influence of Bus Stops on Flow Characteristics of Mixed Traffic. *Journal of Transportation Engineering*, 131(8), 640-643.

Kuhler, M., and Karsten, D. (1978) Improved driving cycle for testing automotive exhaust emissions. *Societies Automotive Engineer*. 780650, Warrendale.

Kumar, R. (2007) Review of the Driving Cycle and its Parametric Comparison for Motorbikes. In: *Making Connection Faculty of Engineering, Computing, and Creative Sciences, Postgraduate Research Conference.* Napier University. Edinburgh. pp. 12-13.

Kumar, R., Saleh, W., and Kirby, H. (2007) Development of driving cycle for motorcycle for Edinburgh. In*: Proceeding of 5th International Conference on World Association for Sustainable Development (WASD)*.7, Brisbane, pp. 357–368.

Larsen, L., et al. Faerdselslov $40 nye former for trafiksanering; Betrenkning nr. 827. Justitsministeriet; 1978.

Liang, W.L., Kyte, M., Kitchener, F., and Shannon, P. (1998) Effect of environmental Factors on Driving Speed: A Case Study. *Transportation Research Record 1635, TRB, National Research Council*, Washington, D. C.

Lin, J., and Niemeier, D.A. (2002) An exploratory analysis comparing a stochastic driving cycle to California's regulatory cycle. *Atmospheric Environment*. 36(38), pp. 5759-5770.

Litman, T. (1999) Reinventing Transportation; Exploring the Paradigm Shifty Needed to Reconcile Sustainability and transportation Objectives, *Transportation Research Board*, pp 8 – 12, 1999

Litman, T., (2003) The Online TDM Encyclopedia: mobility management information gateway. *Original Research Article Transport Policy*, Volume 10, Issue 3, pp. 245-249

Litman, T., (1999) Traffic Calming Benefits, Costs, and Equity Impacts. Victoria Transport Policy Institute, Victoria.

Lyons, T.J., Kenworthy, J.R., Austin, P.I., and Newman, P.W.G. (1986) The development of a driving cycle for fuel consumption and emissions evaluation. *Transportation Research A.* 20 (6), pp. 447–462.

Mannering, F. L., Hamed M., (1990) Commuter welfare approach to high occupancy vehicle lane evaluation: An exploratory analysis. *Original Research Article Transportation Research Part A*: General, Volume 24, Issue 5, pp. 371-379

Manual for Performance Box. (2008) [Online] Available from http://www.performancebox.co.uk/.

Mohring, H., (1979) The benefits of reserved bus lanes. Mass transit subsidies and marginal cost pricing in alleviating traffic congestion. In: *Mieskowosky, P., Straszheim, M. (Eds.)*, Current Issues in Urban Economics.

Montazeri-Gh, M & Naghizadeh, M., (2003) [online] *Development of car drive cycle for simulation of emissions and fuel economy*. Available from http://www.scs-europe.net/services/ess2003/PDF/LOGIS07.pdf [Accessed 24th March 2012].

Mulley, C., Anderson, J., Nelson, J.D. & Wilson, M.. *Why No Car Lanes appear to be the best form of priority lane.* ITTR/CTR Lunchtime Research Seminar. University of Aberdeen , 19 November 2007.

Mulley,C. & Nelson, J.D. (2009) Flexible transport services: A new market opportunity for public transport. *Research in Transportation Economics*, Volume 25, Issue 1, 2009, Pages 39–45

Musallam, N. 'Vehicles Flouting Polution Laws Cause for Concern.' *Khaleej Times*, 2005

Nelson, J.D. (2008) *Transport, Climate Change and the Role of Travel Behaviour* Climate change impacts in the Highlands and Islands Seminar.

Nelson, J.D. & Aditjandra, P.T (2012) *Bridging the mobility gap: The role of ITS in* Grieco, M. and Urry, J., *Motilities: New Perspectives on Transport and Society. Chapter 17:* Ashgate.

Nick, V. *Dubai Traffic, Is there a solution coming up?* Alshandagah Issue 62, 2005.

O'Flaherty, C.A (1997) Transport Planning and Traffic Engineering. *Butterworth-Heinemann*, England.

Office of the Deputy Prime Minister (2005) Planning Policy Statement 1 Creating Sustainable Communities. *Office of Deputy Prime Minister*, England.

OECD (Organisation for Economic Co-operation and Development) (2002) Road Travel Demand, meeting the challenge. *OECD*, France.

OECD (Organisation for Economic Co-Operation and Development) (2011): OECD Environmental outlook to 2050: *OECD*, France. Available from http://www.oecd.org/dataoecd/21/30/49089652.pdf [Accessed 9th May 2010]

Ortúzar and Willumsen, (2001) J. de D. Ortúzar, L.G. Willumsen. Modelling Transport, *(third ed.) John wiley and Sons*, Chichester.

Oxford Business Group. *The Report: Dubai* 2008. 2008

Pearce, D.W. (2000) Economics and environment, essays on ecological and sustainable development. *Edward Edgar Publishing*, England.

Pelkmans, L., Lenaers, G., Debal, P., Hood, T., Hauser, G., and Delgado, M.R. (2002) Comparison of fuel consumption and emissions of modern light duty vehicles in the EU-cycle versus real world driving. In: *Proceedings of Eleventh International Symposium Transport and Air Pollution*. 1, pp. 63–70.

Pelkmans. L., and Debal, P. (2006) Comparison of on-road emission with emissions measured on chassis dynamometer test cycles. *Transportation Research Part D*. 11, pp. 233–241.

Pharoah, T. & Russell, J.(1989): Traffic Calming :policy and evaluations in three European Countries Occasional Paper 2/1989: *South Bank Polytechnic*, London, England

Pharoah, T., (1991) Traffic calming: progress and potential. In: *Highways and Planning Proceedings of PTRC European Transport 19th summer annual meeting*, University of Sussex.

Poe, C. M., J. P. Tarris, J. M. Mason. (1996) Influence of access and Lane Use on Vehicle Operating Speeds along Low-Speed Urban Streets. *Conference Proceedings for the Second National Access Management Conference*, Vail, Colorado, 1996.

Pöǧün, G., Şatir, A., (1986) Alternative bus scheduling policies for an exclusive bus lane *Original Research Article Transportation Research Part A*: General, Volume 20, Issue 6, pp. 437-446

Policy Note, nd., [online], *Edinburgh Greenways (Bus Priority Measures)*. Available from http://www.polisnetwork.eu/uploads/Modules/PublicDocuments/Edinburgh%20GREENWAYS.pdf [Accessed 23rd March 2012].

Polus, A., Livneh, M., and Craus, J. (1984) Effect of Traffic and Geometric Measures on Highway Average Running Speed. *Transportation Research Record 960*. TRB, National Research Council, Washington, D.C., 34-39.

Potter, S. (2008) Purchase, Circulation and Fuel Taxation. Ison, S. & Rye, T.(Editors) *The implementation and effectiveness of transport demand management measures: an international perspective*: Ashgate Publishing, England.

Rakopoulos, C.D & Giakoumis, E.G. (2009) *Diesel Engine Transient Operation, principles of Operation and Simulation Analysis*. Springer, England.

Richardson, H.W and Chang-Hee, C.B. (2008) *Road Congestion pricing in Europe, implications for the United States*. Edward Elgar Publishing , USA.

Rickard Andersson (2009) *The New European Driving Cycle* [online] available from: <http://www.airmaxgroup.com/forums/viewtopic.php?id=63> [Accessed 5th January2010]

Robert Joumard et al,. (2003) Characterizing Real Unit Emissions for Light Duty Goods Vehicles [online] available from http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH3-49NXFV4-2&_user=10&_coverDate=12/31/2003&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=75f969c16a92bd1d069986faa5074206 [Accessed 13th February 2010]

Rodrigue, J., Comtois, C. and Slcak B. (2009) *The Geography of Transport systems*. London, Taylor & Francis, 2009.

Saleh, W. (2007) Success and Failure of travel demand management: Is congestion Charging the way forward? *Transportation Research A* 41, 611-614.

Saleh, W., Kumar, R. & Sharma, A. (2010) Driving cycle for motorcycles in modern cities. Case studies of Edinburgh and Delhi. *World Journal of Science, Technology & Sustainable Development,* Vol. 7, No. 3, 2010 pp. 263-274.

Salter, R.J (1996) *Highway Traffic Analysis and Design*. MacMillan, England.

Sambidge, A. (2008) [online] *Bus Lanes, cycle zones part of $12billion traffic master plan*. Arabian Business.com. Available from http://www.arabianbusiness.com/bus-lanes-cycle-zones-part-of-12bn-traffic-master-plan-82233.html, [Accessed 23th January 2010]

Schafer, A.,Heywood, J.B & Jacoby, H.D. (2009) Transportation in a climate constrained world. *MIT Press,* USA.

Schulte-Peevers, A. *Dubai*. Melbourne; Lonely Planet, 2010.

Scottish Government, (2000) [online] *Comparative evaluation of greenways and conventional bus lanes*. Available from http://www.scotland.gov.uk/Publications/2000/05/fc190343-bf4a-44fb-947f-f2282237e1dc [Accessed 23rd March 2012].

Seisaku, U., &Kiko, K WCTR Society (2004) *Urban Transport and the environment, an international perspective*. Emerald Group Publishing, Holland.

Shafiepour, M., and Kamalanh, H. (2005) Air Quality Deterioration in Tehran Due To Motorcycles. *Iran Journal of Environment and Health Science Engineering*. 2(3), pp. 145-152.

Sheppard, E. (1986) Modelling and predicting aggregate flows. In S. Hanson, (ed), *The Geography of Urban Transportation*. The Guilford Press, New York, 91-118.

Simanaitis, D.J. (1977) Emission test cycles around the world. *Automotive Engineering*. 85, pp. 34–43.

Smith, R. A. (2008) Enabling technologies for demand management. *Transport Original Research Article Energy Policy*, Volume 36, Issue 12, pp. 4444-4448.

Sokhi, R.S., San Jose, R., Moussiopoulos, N. & Berkowicz, R. (Editor) (2000) Urban Air Quality: measurement, modelling and management. *Proceedings of the second international conference o urban air quality: measurement, modelling and management.* Madrid 1999.

Statens Byggeforskningsinstitut. Sikrere Veje. SBI-Byplanlregning 9; 1969.

Statens Vegvesen. Hovedveg i tettsted-Prioritering av lokalsamfunnet-Strategi C. Statens Vegvesen Hindbok 058; 1979.

Steg, L., Vlek, C., (1997) The Role of Problem Awareness in Willingness-to-change Car use and in Evaluating Relevant Policy Measures. In Rothengatter, T., Carbonell Vaya, E. (Eds) Traffic and Transport Psychology. *Pergamon Press*, Oxford, pp. 465-475.

Stradling, S.G., Meadows, M.L., Beattty, S., (2000) Helping drivers out of their cars, Integrating Transport Policy and Social Psychology for Sustainable Change. *Transport Policy* 7, pp. 207-215.

Taylor, D. (1996) Public Attitudes and consultation in traffic calming schemes. *Institute for Transport Studies, University of Leeds; European Transport Conference*, ETC.

Tignor, S.C., and Warren, D. (1990) Driver Speed Behaviour on U.S Streets and Highways. Compendium of Technical Papers, *Institute of Transportation Engineers*, Washington, D.C.

Tong et al. (1999) *Development of a practical driving cycle construction methodology, A case study in Hong Kong* [online] available from http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH8-4N3H164-1&_user=10&_coverDate=03/31/2007&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1255425350&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=dfe3144d4106729ddec4a02fad8a15d9 [Accessed 15th February 2010]

Tong, H.Y (1999) Development of a driving cycle for Hong Kong *Atmospheric Environment* Volume: 33, Issue: 15, Pages: 2323-2335

TfL (Transport for London, UK) (2002) [online] *London Bus Initiative*. Available from http://www.ctc.org.uk/resources/Benchmarking/TfLLBI.pdf [Accessed 23rd March 2012].

TfL (Transport for London, UK) (2005) Traffic Calming measures for bus routes. Transport for London.

TfL (Transport for London, UK) (2007) [online] *Central London Congestion Charging Scheme :ex-post evaluation of the quantified impacts of the original scheme*, available from http://www.tfl.gov.uk/assets/downloads/Ex-post-evaluation-of-quantified-impacts-of-original-scheme-07-June.pdf [Accessed 25th March 2012].

TfL (Transport for London, UK) (2008) [online] *Central London Congestion Charging, Impacts Monitoring*, available from http://www.tfl.gov.uk/assets/downloads/sixth-annual-impacts-monitoring-report-2008-07.pdf [Accessed 25th March 2012]

Tsai, J. H., Chiang, H. L., Chun, H.Y., Penga, B.J., and Hung, R.F. (2005) Development of a local real world driving cycle for motorcycles for emission factor measurements. *Atmospheric Environment*. 39, pp. 6631–6641.

Tyler Miller, G. & Spoolman, S. (2011) Living in the Environment: principles, connections and solutions. *Cengage Learning*, USA.

Tzeng, G.H., and Chen, J.J. (1998) Developing a Taipei motorcycle driving cycle for emissions and fuel economy. *Transportation Research D.*3, pp. 19–27.

Tzeng, H.P., Yang, R.S., Ueng, T.H., Lin-Shiau, S.Y., and Liu, S. (2003) Motorcycle Exhaust Particulates Enhance Vasoconstriction in Organ Culture of Rat Aortas and Involve Reactive Oxygen Species. *Toxicological Sciences.* 75, pp. 66-73.

Tzirakis, E., Pitsas, K., Zannikos, F., Stournas, S. (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, No 3, pp 282-290, 2006

Vasic, A.M., and Weilemann, M. (2006) Comparison of real-world emissions from two-wheelers and passenger cars. *Environment Science Technology*. 40, pp. 149-154.

VTPI, (2003) Online TDM Encyclopedia, Victoria Transport Policy Institute, www.vtpi.org.

W.G Myers: (2002) *Regeneration and Transport Overview and Scrutiny Committee* [online] available from http://www.wandsworth.gov.uk/moderngov/(S(jpfrmg55o3e5ic45yryvmt55))/Data/Regeneration%20and%20Transport%20Overview%20and%20Scrutiny%20Committee/20020221/Agenda/$Paper%20No.%2002-232.doc.pdf [Accessed 6th February 2010]

Wachs, M. (1991). Policy Implications of Recent Behavioral Research in Transportation Demand Management. In *Journal of Planning Literature,* Vol. 5 No. 4, pp. 333-341.

Walker, J. and Butler, S. *Oman, UAE and Arabian Peninsula*, Melbourne; Lonely Planet, 2010.

Wang, C.S., Huang, Q.D., Ling, R.S., and Zhang, Y.T. (1985) Measurement of passenger car operation in Beijing pertinent to exhaust and fuel economy. *SAE Paper,* 852242.

Watson, H.C (1978) *Bureau of Transport Economics, Vehicle Driving Patterns and Measurement Methods for Energy and Emissions*. Assessment: Australian Government Publishing Service, Australia.

Watson, H.C., Milkins, E.E., and Braunsteins, J. (1982) The development of the Melbourne peak cycle. In: *Joint SAE-A/ARRB Second Conference on Traffic, Energy and Emission*. 82148, Melbourne.

White, P. (1995) Public Transport: Its planning, management and operation (3rd edition): *UCL Press*, England.

Zhou, L. (2008) Modelling the impacts of an employer based travel demand management program on commute travel behaviour. *ProQuest University of South Florida*, USA.

Appendices:

1.1 Mixed traffic corridor measurements in Edinburgh

1.1.1 A702 (8.00-9.00 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A702 T(1) 8-9 Am (In) Bus	278.1	14.34	1108.75	0.1308	0.037	0.213	0.617
A702 T(2) 8-9 Am (In) Bus	316.3	14.59	1281.789	0.152	0.03002	0.297	0.519
A702 T(3) 8-9 Am (In) Bus	403.8	14.39	1614.968	0.182	0.195	0.186	0.435
A702 T(4) 8-9 Am (In) Bus	490.9	10.34	1410.305	0.123	0.027	0.296	0.55
A702 T(5) 8-9 Am (In) Bus	398.3	12.78	1414.246	0.105	0.035	0.355	0.503
A702 T(6) 8-9 Am (In) Bus	535.2	9.61	1430.122	0.119	0.072	0.28	0.526
A702 T(7) 8-9 Am (In) Bus	506.6	9.38	1320.265	0.053	0.036	0.281	0.628
A702 T(8) 8-9 Am (In) Bus	317.3	16.407	1446.358	0.203	0.212	0.18	0.403
A702 T(9) 8-9 Am (In) Bus	322.4	17.97	1609.487	0.197	0.143	0.19	0.468
A702 T(10) 8-9 Am (In) Bus	423.5	13.53	1592.152	0.17001	0.102	0.312	0.415
A702 T(1) 8-9 Am (Out) Bus	260.4	18.88	1366.006	0.093	0.031	0.221	0.653
A702 T(2) 8-9 Am (Out) Bus	318	20.12	1777.861	0.205	0.213	0.15	0.43
A702 T(3) 8-9 Am (Out) Bus	498.4	11.71	1621.731	0.104	0.026	0.28	0.588
A702 T(4) 8-9 Am (Out) Bus	441.1	14.47	1773.561	0.103	0.028	0.342	0.524
A702 T(5) 8-9 Am (Out) Bus	228.8	17.18	1092.903	0.109	0.063	0.256	0.57
A702 T(6) 8-9 Am (Out) Bus	344.5	18.39	1760.303	0.207	0.191	0.171	0.429
A702 T(7) 8-9 Am (Out) Bus	374.3	16.34	1699.303	0.165	0.018	0.272	0.544
A702 T(8) 8-9 Am (Out) Bus	293.8	15.23	1243.295	0.101	0.023	0.377	0.497
A702 T(9) 8-9 Am (Out) Bus	402.6	15.88	1776.589	0.202	0.194	0.255	0.347
A702 T(10) 8-9 Am (Out) Bus	348	15.81	1528.255	0.154	0.032	0.328	0.483
Average	375.12	14.867	1493.413	0.1438905	0.085401	0.2621	0.50645
SD	87.491	3.0154	216.4553	0.045921856	0.074837573	0.0654	0.08172
COV	0.2332	0.2028	0.14494	0.31914446	0.876307924	0.2496	0.16136

1.1.2 A702 (2.00-3.00 pm) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A702 T(1) 2-3 Pm (In) Bus	409.5	11.62	1322.612	0.088	0.037	0.296	0.578
A702 T(2) 2-3 Pm (In) Bus	379.1	15.15	1596.367	0.195	0.2002	0.159	0.444
A702 T(3) 2-3 Pm (In) Bus	351.8	13.16	1286.523	0.1003	0.0309	0.302	0.565
A702 T(4) 2-3 Pm (In) Bus	404.8	13.92	1566.231	0.143	0.079	0.225	0.551
A702 T(5) 2-3 Pm (In) Bus	385.1	10.58	1132.277	0.1002	0.035	0.291	0.572
A702 T(6) 2-3 Pm (In) Bus	409.6	12.42	1413.615	0.103	0.032	0.29	0.574
A702 T(7) 2-3 Pm (In) Bus	376.1	14.63	1528.904	0.124	0.034	0.284	0.556
A702 T(8) 2-3 Pm (In) Bus	506.9	11.92	1679.998	0.148	0.08007	0.348	0.422
A702 T(9) 2-3 Pm (In) Bus	368.1	14.75	1508.77	0.136	0.087	0.265	0.51
A702 T(10) 2-3 Pm (In) Bus	463.1	11.49	1478.737	0.045	0.039	0.296	0.618
A702 T(1) 2-3 Pm (Out) Bus	362.1	18.9	1901.413	0.197	0.152	0.183	0.466
A702 T(2) 2-3 Pm (Out) Bus	361.2	14.48	1453.937	0.074	0.025	0.295	0.603
A702 T(3) 2-3 Pm (Out) Bus	474.1	12.94	1704.455	0.146	0.072	0.297	0.482
A702 T(4) 2-3 Pm (Out) Bus	300.5	20.32	1696.53	0.198	0.156	0.182	0.463
A702 T(5) 2-3 Pm (Out) Bus	380.5	15.15	1602.072	0.161	0.029	0.316	0.491
A702 T(6) 2-3 Pm (Out) Bus	335.8	17.02	1588.298	0.171	0.128	0.194	0.506
A702 T(7) 2-3 Pm (Out) Bus	299.7	19.102	1590.227	0.162	0.121	0.168	0.547
A702 T(8) 2-3 Pm (Out) Bus	318.9	17.72	1570.285	0.129	0.03009	0.3	0.54
A702 T(9) 2-3 Pm (Out) Bus		16.41		0.127	0.027		
A702 T(10) 2-3 Pm (Out) Bus	396.5	15.54	1711.962	0.115	0.031	0.312	0.541
Average	383.34	14.861	1543.853	0.133125	0.071263	0.2633	0.52784
SD	54.972	2.7381	174.8846	0.041351394	0.053159719	0.058	0.05492
COV	0.1434	0.1842	0.113278	0.310620798	0.745965219	0.2204	0.10404

1.1.3 A702 (8.00-9.00 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A702 T(1) 8-9 Am (In) Car	288.5	17.05	1366.83	0.141	0.183	0.145	0.529
A702 T(2) 8-9 Am (In) Car	297.6	16.76	1386	0.094	0.027	0.222	0.655
A702 T(3) 8-9 Am (In) Car	203.6	27.55	1558.78	0.189	0.113	0.091	0.605
A702 T(4) 8-9 Am (In) Car	263.1	18.88	1380.21	0.165	0.129	0.21	0.493
A702 T(5) 8-9 Am (In) Car	286	16.19	1287.07	0.167	0.182	0.197	0.452
A702 T(6) 8-9 Am (In) Car	232.1	16.64	1073.25	0.111	0.033	0.172	0.681
A702 T(7) 8-9 Am (In) Car	228.5	24.19	1535.73	0.194	0.087	0.097	0.62
A702 T(8) 8-9 Am (In) Car	252.5	20.86	1463.03	0.196	0.192	0.096	0.514
A702 T(9) 8-9 Am (In) Car	258.5	22.29	1600.57	0.136	0.099	0.168	0.594
A702 T(10) 8-9 Am (In) Car	226.4	25.04	1575.15	0.156	0.015	0.139	0.688
A702 T(1) 8-9 Am (Out) Car	276.9	19.72	1517.77	0.153	0.047	0.2	0.597
A702 T(2) 8-9 Am (Out) Car	280.8	21.402	1669.27	0.183	0.154	0.149	0.512
A702 T(3) 8-9 Am (Out) Car	337.1	16.83	1576.18	0.153	0.096	0.243	0.506
A702 T(4) 8-9 Am (Out) Car	219	27.78	1690.24	0.223	0.035	0.116	0.624
A702 T(5) 8-9 Am (Out) Car		22.67		0.087	0.057		
A702 T(6) 8-9 Am (Out) Car	244.3	25.22	1711.61	0.163	0.085	0.143	0.607
A702 T(7) 8-9 Am (Out) Car	222.7	26.35	1630.68	0.196	0.192	0.042	0.569
A702 T(8) 8-9 Am (Out) Car	284.8	21.92	1734.18	0.182	0.157	0.205	0.454
A702 T(9) 8-9 Am (Out) Car	312.5	19.17	1664.44	0.169	0.082	0.221	0.526
A702 T(10) 8-9 Am (Out) Car	307	19.45	1658.85	0.185	0.138	0.17	0.505
Average	264.31	21.298	1530.52	0.16215	0.10515	0.1593	0.56479
SD	36.712	3.7732	169.415	0.035097271	0.058620344	0.0538	0.07227
COV	0.1389	0.1772	0.11069	0.216449404	0.557492573	0.3375	0.12796

1.1.4 A702 (2.00-3.00 pm) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A702 T(1) 2-3 Pm (In) Car	270.8	18.38	1383	0.1406	0.051	0.303	0.504
A702 T(2) 2-3 Pm (In) Car	264.3	21.55	1582.95	0.166	0.154	0.173	0.505
A702 T(3) 2-3 Pm (In) Car	181.2	28.62	1440.87	0.209	0.092	0.054	0.644
A702 T(4) 2-3 Pm (In) Car	273.2	21.75	1651.54	0.199	0.203	0.086	0.51
A702 T(5) 2-3 Pm (In) Car	260.1	22.802	1647.5	0.177	0.119	0.123	0.579
A702 T(6) 2-3 Pm (In) Car	289.2	19.74	1586.32	0.201	0.187	0.124	0.486
A702 T(7) 2-3 Pm (In) Car	262.9	20.94	1529.19	0.177	0.166	0.149	0.506
A702 T(8) 2-3 Pm (In) Car	271	21.72	1635.23	0.2002	0.188	0.089	0.521
A702 T(9) 2-3 Pm (In) Car	237	24.23	1595.95	0.133	0.112	0.171	0.582
A702 T(10) 2-3 Pm (In) Car	284	20.73	1635.67	0.186	0.2007	0.113	0.499
A702 T(1) 2-3 Pm (Out) Car	195	25.59	1386.7	0.125	0.031	0.104	0.738
A702 T(2) 2-3 Pm (Out) Car	276.7	22.38	1721.24	0.143	0.091	0.118	0.647
A702 T(3) 2-3 Pm (Out) Car	342.4	16.84	1602.6	0.133	0.0809	0.253	0.531
A702 T(4) 2-3 Pm (Out) Car	274.3	21.38	1629.63	0.163	0.053	0.203	0.577
A702 T(5) 2-3 Pm (Out) Car	328.4	14.701	1341.03	0.057	0.029	0.307	0.605
A702 T(6) 2-3 Pm (Out) Car	441.7	13.92	1707.96	0.184	0.198	0.291	0.326
A702 T(7) 2-3 Pm (Out) Car	431.9	14.01	1680.52	0.177	0.135	0.281	0.405
A702 T(8) 2-3 Pm (Out) Car	365.3	16.38	1662.64	0.199	0.199	0.169	0.43
A702 T(9) 2-3 Pm (Out) Car	268.2	24.13	1798.51	0.177	0.021	0.244	0.556
A702 T(10) 2-3 Pm (Out) Car	264.3	23.01	1689.68	0.195	0.199	0.104	0.5
Average	289.09	20.64	1595.44	0.16709	0.12548	0.173	0.53255
SD	65.53	3.9292	121.956	0.03654128	0.065874159	0.0805	0.09085
COV	0.2267	0.1904	0.07644	0.218692203	0.52497736	0.4656	0.1706

1.2 Bus lane corridor measurements in Edinburgh

1.2.1 A7 (6.30-730 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 6.30-7.30 Am (In) Bus	175	21.84	1062.358	0.081	0.051	0.135	0.73
A7 T(2) 6.30-7.30 Am (In) Bus	179.9	20.59	1029.729	0.0505	0.037	0.214	0.697
A7 T(3) 6.30-7.30 Am (In) Bus	183.5	17.48	891.2685	0.181	0.0403	0.342	0.435
A7 T(4) 6.30-7.30 Am (In) Bus	173.4	13.62	656.4729	0.051	0.036	0.318	0.59
A7 T(5) 6.30-7.30 Am (In) Bus	242.9	17.09	1153.578	0.044	0.047	0.319	0.588
A7 T(6) 6.30-7.30 Am (In) Bus	231.9	17.97	1158.194	0.119	0.031	0.156	0.691
A7 T(7) 6.30-7.30 Am (In) Bus	137	14.88	566.7378	0.053	0.041	0.35	0.554
A7 T(1) 6.30-7.30 Am (Out) Bus	249.7	19.95	1384.495	0.112	0.024	0.139	0.724
A7 T(2) 6.30-7.30 Am (Out) Bus	261.4	18.28	1327.427	0.147	0.024	0.217	0.611
A7 T(3) 6.30-7.30 Am (Out) Bus	286.9	19.601	1562.343	0.173	0.182	0.122	0.521
A7 T(4) 6.30-7.30 Am (Out) Bus	187.7	24.41	1273.018	0.169	0.186	0.071	0.572
A7 T(5) 6.30-7.30 Am (Out) Bus	273.9	16.57	1261.226	0.102	0.027	0.291	0.577
A7 T(6) 6.30-7.30 Am (Out) Bus	283.1	19.66	1546.203	0.1903	0.211	0.136	0.461
A7 T(7) 6.30-7.30 Am (Out) Bus	373.8	14.14	1468.798	0.191	0.158	0.222	0.427
A7 T(8) 6.30-7.30 Am (Out) Bus	232.9	21.908	1417.4	0.152	0.127	0.156	0.563
A7 T(9) 6.30-7.30 Am (Out) Bus	188.7	25.39	1331.439	0.217	0.019	0.11	0.653
Average	228.86	18.961	1193.168	0.12705	0.07758125	0.2061	0.58713
SD	59.576	3.404	293.2745	0.058336438	0.068806727	0.0917	0.09592
COV	0.2603	0.1795	0.245795	0.459161259	0.886898917	0.4449	0.16337

1.2.2 A7 (8.00-9.00 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 8-9 Am (In) Bus	395.1	10.67	1171.896	0.0903	0.025	0.462	0.421
A7 T(2) 8-9 Am (In) Bus	381.7	12.79	1356.318	0.197	0.205	0.318	0.278
A7 T(3) 8-9 Am (In) Bus	348.6	14.39	1394.026	0.206	0.2001	0.235	0.357
A7 T(4) 8-9 Am (In) Bus	351.1	13.06	1274.03	0.105	0.025	0.379	0.49
A7 T(5) 8-9 Am (In) Bus	296.8	13.51	1114.417	0.093	0.021	0.351	0.532
A7 T(6) 8-9 Am (In) Bus	458.1	9.96	1268.087	0.062	0.031	0.46	0.445
A7 T(7) 8-9 Am (In) Bus	437.9	11.66	1419.4	0.192	0.175	0.316	0.315
A7 T(8) 8-9 Am (In) Bus	446.9	10.09	1253.298	0.117	0.023	0.462	0.395
A7 T(9) 8-9 Am (In) Bus	397.2	12.61	1391.928	0.176	0.177	0.238	0.407
A7 T(10) 8-9 Am (In) Bus	343.8	13.99	1336.209	0.198	0.196	0.227	0.377
A7 T(1) 8-9 Am (Out) Bus	469.5	11.81	1540.302	0.186	0.105	0.303	0.404
A7 T(2) 8-9 Am (Out) Bus	300.8	18.94	1582.93	0.211	0.202	0.277	0.309
A7 T(3) 8-9 Am (Out) Bus	334.3	14.83	1377.653	0.199	0.206	0.217	0.376
A7 T(4) 8-9 Am (Out) Bus	296.6	17.21	1418.008	0.217	0.165	0.275	0.341
A7 T(5) 8-9 Am (Out) Bus	386.1	14.03	1505.383	0.175	0.151	0.287	0.385
A7 T(6) 8-9 Am (Out) Bus	326.3	16.21	1469.551	0.202	0.193	0.152	0.451
A7 T(7) 8-9 Am (Out) Bus	356.2	14.93	1478.141	0.205	0.109	0.191	0.493
A7 T(8) 8-9 Am (Out) Bus	354.1	14.13	1390.352	0.184	0.082	0.282	0.451
A7 T(9) 8-9 Am (Out) Bus	333.5	16.56	1534.91	0.202	0.217	0.279	0.301
A7 T(10) 8-9 Am (Out) Bus	384.6	14.25	1522.901	0.172	0.041	0.336	0.449
Average	369.96	13.782	1389.987	0.169465	0.127455	0.3024	0.39885
SD	52.396	2.3448	126.1262	0.04745489	0.075962411	0.0873	0.06927
COV	0.1416	0.1701	0.090739	0.280027677	0.595993966	0.2888	0.17366

1.2.3 A7 (2.00-3.00 pm) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 2-3 Pm (In) Bus	374.2	11.67	1213.735	0.112	0.021	0.394	0.472
A7 T(2) 2-3 Pm (In) Bus	519.9	9.17	1325.34	0.181	0.121	0.399	0.296
A7 T(3) 2-3 Pm (In) Bus	409	11.35	1289.577	0.193	0.202	0.279	0.324
A7 T(4) 2-3 Pm (In) Bus	389.5	12.76	1381.641	0.181	0.175	0.203	0.439
A7 T(5) 2-3 Pm (In) Bus		14.54		0.188	0.1408		
A7 T(6) 2-3 Pm (In) Bus	429.8	10.46	1249.966	0.136	0.030006	0.481	0.351
A7 T(7) 2-3 Pm (In) Bus	320	15.71	1396.715	0.185	0.211	0.281	0.322
A7 T(8) 2-3 Pm (In) Bus	409.8	11.26	1282.26	0.174	0.1607	0.334	0.329
A7 T(9) 2-3 Pm (In) Bus	462.7	10.05	1292.682	0.137	0.094	0.412	0.355
A7 T(10) 2-3 Pm (In) Bus	457	10.97	1393.25	0.103	0.052	0.403	0.44
A7 T(1) 2-3 Pm (Out) Bus	438.6	12.55	1530.11	0.176	0.122	0.234	0.467
A7 T(2) 2-3 Pm (Out) Bus	352.6	14.301	1401.095	0.205	0.211	0.237	0.346
A7 T(3) 2-3 Pm (Out) Bus	383.5	12.42	1323.764	0.146	0.017	0.412	0.423
A7 T(4) 2-3 Pm (Out) Bus	289	16.56	1330.192	0.215	0.171	0.291	0.321
A7 T(5) 2-3 Pm (Out) Bus	396	13.94	1533.784	0.1906	0.096	0.211	0.501
A7 T(6) 2-3 Pm (Out) Bus	331.5	16.84	1551.404	0.195	0.198	0.232	0.372
A7 T(7) 2-3 Pm (Out) Bus	371.4	14.81	1528.602	0.188	0.1109	0.173	0.527
A7 T(8) 2-3 Pm (Out) Bus	361.1	15.23	1528.543	0.176	0.065	0.238	0.519
A7 T(9) 2-3 Pm (Out) Bus	431.7	12.49	1497.869	0.203	0.203	0.24	0.352
A7 T(10) 2-3 Pm (Out) Bus	296.9	18.45	1522.313	0.194	0.141	0.214	0.448
Average	390.75	13.277	1398.571	0.17393	0.1271203	0.2983	0.40021
SD	59.243	2.4969	112.2358	0.030831855	0.065252097	0.0914	0.07472
COV	0.1516	0.1881	0.08025	0.177265881	0.513309808	0.3063	0.18671

1.2.4 A7 (6.30-7.30 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 6.30-7.30 Am (In) Car	162.7	32.84	1484.82	0.186	0.2002	0.048	0.564
A7 T(2) 6.30-7.30 Am (In) Car	161.1	31.71	1419.31	0.186	0.194	0.049	0.568
A7 T(3) 6.30-7.30 Am (In) Car	148.4	34.85	1436.87	0.188	0.193	0.016	0.6
A7 T(4) 6.30-7.30 Am (In) Car	174.1	29.06	1405.77	0.159	0.148	0.065	0.626
A7 T(5) 6.30-7.30 Am (In) Car	162.2	32.68	1472.85	0.192	0.166	0.089	0.55
A7 T(6) 6.30-7.30 Am (In) Car	145.3	35.102	1416.85	0.177	0.1905	0.037	0.594
A7 T(7) 6.30-7.30 Am (In) Car	150.8	35.58	1490.49	0.196	0.194	0.017	0.591
A7 T(8) 6.30-7.30 Am (In) Car	168	28.96	1351.64	0.209	0.183	0.109	0.497
A7 T(9) 6.30-7.30 Am (In) Car	194.8	26.74	1446.95	0.205	0.182	0.188	0.423
A7 T(1) 6.30-7.30 Am (Out) Car	175.2	30.84	1501.32	0.195	0.199	0.141	0.463
A7 T(2) 6.30-7.30 Am (Out) Car	188.3	28.25	1477.62	0.1804	0.071	0.073	0.675
A7 T(3) 6.30-7.30 Am (Out) Car	176.9	28.79	1414.59	0.199	0.191	0.089	0.519
A7 T(4) 6.30-7.30 Am (Out) Car	197.3	23.57	1292.13	0.196	0.208	0.086	0.508
A7 T(5) 6.30-7.30 Am (Out) Car	135.5	48.59	1827.31	0.084	0.056	0	0.859
A7 T(6) 6.30-7.30 Am (Out) Car	149.9	35.09	1461.57	0.17	0.214	0.018	0.598
A7 T(7) 6.30-7.30 Am (Out) Car	139	37.27	1439.02	0.187	0.186	0.013	0.611
A7 T(8) 6.30-7.30 Am (Out) Car	169.8	32.19	1518.53	0.193	0.198	0.046	0.562
A7 T(9) 6.30-7.30 Am (Out) Car	197.4	26.92	1476.68	0.206	0.204	0.088	0.5
Average	166.48	32.168	1463.02	0.1838	0.176538889	0.0651	0.57267
SD	19.573	5.4881	106.211	0.027911878	0.04386588	0.0488	0.09461
COV	0.1176	0.1706	0.0726	0.151860055	0.248477152	0.7502	0.16521

1.2.5 A7 (8.00-9.00 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 8-9 Am (In) Car	182.9	27.07	1375.23	0.1803	0.141	0.065	0.613
A7 T(2) 8-9 Am (In) Car	210.8	25.51	1494.64	0.187	0.164	0.041	0.606
A7 T(3) 8-9 Am (In) Car	237.8	22.38	1479.14	0.206	0.189	0.093	0.509
A7 T(4) 8-9 Am (In) Car	256.9	20.24	1444.25	0.1906	0.203	0.095	0.51
A7 T(5) 8-9 Am (In) Car	270.1	19.95	1497.53	0.227	0.225	0.092	0.454
A7 T(6) 8-9 Am (In) Car	224.8	23.22	1450.24	0.215	0.199	0.093	0.492
A7 T(7) 8-9 Am (In) Car	309.8	15.77	1357.4	0.184	0.189	0.169	0.457
A7 T(8) 8-9 Am (In) Car	304.3	17.63	1490.91	0.197	0.206	0.162	0.432
A7 T(9) 8-9 Am (In) Car	252.8	20.407	1433.38	0.1905	0.058	0.168	0.582
A7 T(1) 8-9 Am (Out) Car	219.9	24.94	1524.27	0.181	0.197	0.116	0.504
A7 T(2) 8-9 Am (Out) Car	220.8	25.209	1546.33	0.205	0.177	0.152	0.463
A7 T(3) 8-9 Am (Out) Car	260.2	21.46	1552.05	0.196	0.189	0.122	0.491
A7 T(4) 8-9 Am (Out) Car	202.2	26.61	1495.19	0.197	0.224	0.069	0.508
A7 T(5) 8-9 Am (Out) Car	244.7	23.19	1576.49	0.196	0.194	0.041	0.566
A7 T(6) 8-9 Am (Out) Car	282.4	18.7	1466.74	0.184	0.19008	0.2	0.424
A7 T(7) 8-9 Am (Out) Car	195.5	28.109	1526.51	0.207	0.203	0.06	0.528
A7 T(8) 8-9 Am (Out) Car	171.4	24.609	1171.53	0.187	0.175	0.044	0.592
A7 T(9) 8-9 Am (Out) Car	295.9	17.79	1462.88	0.132	0.061	0.194	0.611
Average	241.29	22.377	1463.59	0.192355556	0.176893333	0.1098	0.519
SD	41.246	3.5932	92.3606	0.019499358	0.047009312	0.0531	0.06245
COV	0.1709	0.1606	0.06311	0.101371432	0.265749482	0.4833	0.12032

1.2.6 A7 (2.00-3.00 pm) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
A7 T(1) 2-3 Pm (In) Car	232.8	22.51	1455.81	0.166	0.038	0.129	0.665
A7 T(2) 2-3 Pm (In) Car	256.7	19.71	1405.32	0.171	0.091	0.122	0.614
A7 T(3) 2-3 Pm (In) Car	298	17.86	1479.24	0.185	0.195	0.138	0.48
A7 T(4) 2-3 Pm (In) Car	286.1	18.23	1449.04	0.213	0.203	0.155	0.427
A7 T(5) 2-3 Pm (In) Car	266.1	19.87	1469.03	0.19008	0.199	0.148	0.462
A7 T(6) 2-3 Pm (In) Car	361.5	14.58	1464.03	0.1703	0.192	0.261	0.375
A7 T(7) 2-3 Pm (In) Car	299.3	17.01	1414.25	0.1706	0.181	0.172	0.474
A7 T(8) 2-3 Pm (In) Car	326.1	15.75	1426.78	0.1401	0.129	0.227	0.503
A7 T(9) 2-3 Pm (In) Car	349.5	15.24	1480.13	0.182	0.196	0.275	0.346
A7 T(10) 2-3 Pm (In) Car	185.7	27.14	1400.85	0.186	0.181	0.054	0.577
A7 T(1) 2-3 Pm (Out) Car	333.3	16.92	1567.26	0.165	0.194	0.205	0.434
A7 T(2) 2-3 Pm (Out) Car	260.5	20.71	1498.45	0.2006	0.158	0.125	0.515
A7 T(3) 2-3 Pm (Out) Car	311.4	18.22	1576.76	0.196	0.206	0.139	0.456
A7 T(4) 2-3 Pm (Out) Car	215.2	25.58	1529.67	0.209	0.207	0.061	0.521
A7 T(5) 2-3 Pm (Out) Car	319.3	17.72	1572.33	0.179	0.112	0.169	0.539
A7 T(6) 2-3 Pm (Out) Car	317.5	17.69	1560.84	0.1908	0.196	0.219	0.392
A7 T(7) 2-3 Pm (Out) Car	292.9	18.58	1512.12	0.193	0.211	0.11	0.483
A7 T(8) 2-3 Pm (Out) Car	314.2	17.88	1561.13	0.198	0.143	0.138	0.518
A7 T(9) 2-3 Pm (Out) Car	328	16.801	1530.96	0.184	0.166	0.156	0.492
A7 T(10) 2-3 Pm (Out) Car	226.9	22.35	1409.08	0.2004	0.187	0.125	0.487
Average	289.05	19.018	1488.15	0.184494	0.16925	0.1564	0.488
SD	47.221	3.26	60.5561	0.017308814	0.045556067	0.0578	0.07659
COV	0.1634	0.1714	0.04069	0.09381776	0.269164356	0.3693	0.15695

1.3 Bus only corridor measurements in Edinburgh

1.3.1 Princes Street (8.00-9.00 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Princes St T(1) 8-9 Am (In)	278.4	14.84	1147.73	0.208	0.199	0.24	0.35
Princes St T(2) 8-9 Am (In)	361.9	9.48	953.611	0.177	0.2	0.401	0.22
Princes St T(3) 8-9 Am (In)	283.6	13.27	1046.07	0.1804	0.139	0.224	0.455
Princes St T(4) 8-9 Am (In)	160.8	22.52	1006.82	0.228	0.211	0.115	0.444
Princes St T(5) 8-9 Am (In)	256.3	15.94	1135.62	0.191	0.211	0.285	0.311
Princes St T(6) 8-9 Am (In)	330.1	12.13	1112.89	0.186	0.1904	0.282	0.339
Princes St T(7) 8-9 Am (In)	242.7	16.78	1131.75	0.206	0.205	0.17	0.418
Princes St T(8) 8-9 Am (In)	379.1	11.07	1166.61	0.185	0.201	0.347	0.265
Princes St T(9) 8-9 Am (In)	320.3	12.23	1088.45	0.207	0.218	0.28	0.293
Princes St T(10) 8-9 Am (In)	252	16.0008	1120.49	0.201	0.209	0.158	0.431
Princes St T(1) 8-9 Am (Out)	178.4	16.64	825.174	0.214	0.215	0.189	0.38
Princes St T(2) 8-9 Am (Out)	190.7	17.02	902.179	0.186	0.012	0.241	0.559
Princes St T(3) 8-9 Am (Out)	279.2	13.51	1047.78	0.195	0.113	0.324	0.366
Princes St T(4) 8-9 Am (Out)	259.6	10.41	751.24	0.179	0.125	0.419	0.275
Princes St T(5) 8-9 Am (Out)	159	16.85	744.576	0.192	0.228	0.117	0.461
Princes St T(6) 8-9 Am (Out)	282.1	15.87	1244.59	0.1909	0.206	0.177	0.425
Princes St T(7) 8-9 Am (Out)	359.9	12.48	1248.7	0.198	0.198	0.291	0.311
Princes St T(8) 8-9 Am (Out)		15.66		0.198	0.216		
Princes St T(9) 8-9 Am (Out)	233.1	18.85	1221.05	0.216	0.197	0.15	0.435
Princes St T(10) 8-9 Am (Out)	261.8	16.85	1226.51	0.211	0.203	0.131	0.453
Average	266.79	14.92	1059.04	0.197465	0.18482	0.239	0.378474
SD	65.227	3.12535	158.094	0.013784899	0.051165116	0.0924	0.085771
COV	0.2445	0.20947	0.14928	0.06980933	0.276837548	0.3865	0.226624

1.3.2 Princes Street (2.00-3.00 pm) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Princes St T(1) 2-3 Pm (In)	260.4	15.98	1156.07	0.206	0.218	0.157	0.417
Princes St T(2) 2-3 Pm (In)	229	17.31	1101.4	0.206	0.211	0.154	0.427
Princes St T(3) 2-3 Pm (In)	249.8	15.46	1073.42	0.198	0.204	0.102	0.494
Princes St T(4) 2-3 Pm (In)	281	13.77	1075.37	0.189	0.196	0.23	0.383
Princes St T(5) 2-3 Pm (In)	226.4	16.606	1044.34	0.2105	0.187	0.149	0.452
Princes St T(6) 2-3 Pm (In)	229.3	17.37	1107.38	0.201	0.158	0.199	0.44
Princes St T(7) 2-3 Pm (In)	188.3	20.99	1098.85	0.225	0.214	0.093	0.467
Princes St T(8) 2-3 Pm (In)	206	18.304	1047.49	0.2207	0.198	0.137	0.442
Princes St T(9) 2-3 Pm (In)	252.6	16.38	1150.05	0.216	0.201	0.166	0.414
Princes St T(10) 2-3 Pm (In)	230.3	15.24	975.511	0.198	0.154	0.104	0.542
Princes St T(1) 2-3 Pm (Out)	233.8	19	1234.39	0.193	0.186	0.112	0.508
Princes St T(2) 2-3 Pm (Out)	199	18.46	1020.86	0.207	0.216	0.124	0.451
Princes St T(3) 2-3 Pm (Out)	198.1	19.76	1086.96	0.196	0.213	0.074	0.514
Princes St T(4) 2-3 Pm (Out)		19.608		0.077	0.015		
Princes St T(5) 2-3 Pm (Out)	222.3	20.34	1256.62	0.204	0.2109	0.116	0.468
Princes St T(6) 2-3 Pm (Out)	218.2	21.04	1275.64	0.216	0.178	0.162	0.442
Princes St T(7) 2-3 Pm (Out)	218.2	20.38	1236	0.213	0.218	0.132	0.435
Princes St T(8) 2-3 Pm (Out)	249	18.32	1267.83	0.187	0.182	0.244	0.385
Princes St T(9) 2-3 Pm (Out)	228.8	19.82	1260.77	0.208	0.212	0.106	0.472
Princes St T(10) 2-3 Pm (Out)	247.3	17.68	1215.14	0.2008	0.171	0.215	0.411
Average	229.88	18.0909	1141.27	0.1986	0.187145	0.1461	0.450737
SD	23.273	2.06658	94.7671	0.030349005	0.045016833	0.0478	0.042527
COV	0.1012	0.11423	0.08304	0.152814728	0.240545207	0.3274	0.09435

1.4 Traffic calming measurements in Edinburgh

1.4.1 Corridor 1 = Iona Street (20mph zone)

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Rout 1-1	63.2	22.58	397.0482	0.156	0.199	0.015	0.628
Rout 1-2	58.9	24.29	398.0878	0.177	0.205	0.032	0.584
Rout 1-3	49.9	25.41	352.4751	0.176	0.148	0.01	0.666
Rout 1-4	59.4	23.71	392.0386	0.171	0.159	0.025	0.643
Rout 1-5	54.8	25.88	394.7522	0.151	0.165	0.032	0.65
Rout 1-6	62.5	22.84	397.3163	0.194	0.162	0.025	0.616
Rout 1-7	68	21.07	398.734	0.187	0.162	0.03	0.618
Rout 1-8	61.5	22.83	390.7543	0.202	0.155	0.032	0.608
Rout 1-9	50.3	23.71	331.5972	0.212	0.184	0.019	0.583
Rout 1-10	59.3	24.23	399.9322	0.222	0.171	0.033	0.572
Rout 1-11	91.3	25.45	646.236	0.192	0.141	0.025	0.641
Rout 1-12	56.5	25.51	401.1704	0.21	0.206	0.035	0.545
Rout 1-13	60	22.32	372.6211	0.173	0.188	0.038	0.6
Rout 1-14	50.2	23.92	333.9104	0.133	0.176	0.011	0.677
Rout 1-15	50.2	25.62	357.6217	0.165	0.182	0.023	0.628
Rout 1-16	50.1	27.62	384.8092	0.175	0.149	0.013	0.661
Rout 1-17	50.1	24.12	336.0207	0.149	0.181	0.017	0.651
Rout 1-18	62.6	22.45	391.0306	0.181	0.192	0.022	0.602
Rout 1-19	50.2	26.07	363.8682	0.155	0.18	0.017	0.646
Rout 1-20	62.8	22.93	400.6872	0.174	0.163	0.036	0.624
Average	58.59	24.128	392.0356	0.17775	0.1734	0.0245	0.62215
SD	9.62141	1.61576	64.53229	0.023071685	0.018989	0.00877	0.034095
COV	0.16422	0.06697	0.164608	0.129798507	0.109508	0.35816	0.054801

1.4.2 Corridor 2 = West Bryson Road (20mph zone)

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Rout 2-1	109.6	22.18	676.1029	0.184	0.142	0.027	0.646
Rout 2-2	103.5	22.41	644.9514	0.182	0.165	0.02	0.632
Rout 2-3	102.7	22.42	640.3258	0.17	0.143	0.017	0.668
Rout 2-4	112.9	20.55	645.1824	0.182	0.137	0.019	0.661
Rout 2-5	103.6	22.36	644.1969	0.153	0.143	0.028	0.673
Rout 2-6	87.6	24.89	606.1071	0.171	0.164	0.007	0.656
Rout 2-7	87.8	23.94	584.4399	0.153	0.154	0.012	0.679
Rout 2-8	83.5	28.109	652.7531	0.177	0.144	0.016	0.661
Rout 2-9	101.9	23.35	661.7493	0.179	0.16	0.015	0.644
Rout 2-10	99.9	23.88	663.4382	0.177	0.142	0.033	0.648
Rout 2-11	108.9	21.801	660.0786	0.195	0.155	0.023	0.624
Rout 2-12	103.8	23.55	679.8031	0.191	0.16	0.025	0.621
Rout 2-13	101.9	22.56	639.2557	0.175	0.134	0.046	0.643
Rout 2-14	96.6	23.82	640.0065	0.166	0.13	0.024	0.678
Rout 2-15	92.7	24.72	637.234	0.174	0.149	0.017	0.658
Rout 2-16	81.6	28.11	638.0754	0.162	0.151	0.031	0.653
Rout 2-17	101.3	22.12	623.1565	0.187	0.135	0.026	0.65
Rout 2-18	94.7	24.58	647.33	0.186	0.147	0.028	0.637
Rout 2-19	82.5	28.305	649.4301	0.154	0.13	0.058	0.656
Rout 2-20	97.7	23.75	645.4143	0.157	0.129	0.02	0.692
Average	97.735	23.8703	643.9516	0.17375	0.1457	0.0246	0.654
SD	9.20219	2.1488	21.68666	0.012809844	0.01137	0.01157	0.018388
COV	0.09415	0.09002	0.033677	0.073725721	0.078036	0.47027	0.028116

1.4.3 Corridor 3 = Montgomery Street (20mp zone)

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Rout 3-1	91.4	26.34	669.6565	0.172	0.183	0.014	0.629
Rout 3-2	83.4	29.07	674.3857	0.167	0.178	0.025	0.628
Rout 3-3	89.7	26.609	663.7397	0.152	0.188	0.011	0.648
Rout 3-4	50.1	25.47	649.4708	0.147	0.118	0.019	0.713
Rout 3-5	82.6	29.04	667.2379	0.172	0.171	0.015	0.639
Rout 3-6	94.5	25.44	668.6479	0.131	0.175	0.019	0.674
Rout 3-7	89.3	26.77	664.8189	0.183	0.168	0.029	0.618
Rout 3-8	93.4	25.98	674.9332	0.164	0.177	0.017	0.64
Rout 3-9	92	25.92	663.1568	0.196	0.176	0.018	0.608
Rout 3-10	90.7	26.73	674.1929	0.175	0.176	0.016	0.632
Rout 3-11	97.8	24.77	673.6957	0.205	0.175	0.033	0.585
Rout 3-12	92.1	25.95	664.5975	0.17	0.177	0.02	0.631
Rout 3-13	88.2	27.05	663.5547	0.16	0.191	0.015	0.631
Rout 3-14	82.6	29.34	674.1622	0.159	0.206	0.015	0.617
Rout 3-15	76.3	31.59	670.5035	0.164	0.18	0.019	0.634
Rout 3-16	83.8	27.48	640.5039	0.15	0.184	0.032	0.632
Rout 3-17	80.7	29.89	671.0179	0.142	0.172	0.025	0.659
Rout 3-18	87.6	27.81	677.5717	0.182	0.164	0.012	0.64
Rout 3-19	74.9	30.42	633.2689	0.158	0.178	0.01	0.652
Rout 3-20	85.4	28.39	674.4058	0.185	0.176	0.03	0.607
Average	85.325	27.503	665.6761	0.1667	0.17565	0.0197	0.63585
SD	10.2157	1.87184	11.76537	0.0181488	0.016255	0.007	0.026609
COV	0.11973	0.06806	0.017674	0.108871027	0.092545	0.35518	0.041848

1.4.4 Corridor 4 = Polwarth Terrace (20mph ISA)

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Rout 4-1	49.9	30.61	424.7799	0.16	0.206	0.016	0.618
Rout 4-2	56	29.51	459.9103	0.151	0.196	0.028	0.623
Rout 4-3	59.1	27.99	460.289	0.168	0.138	0.025	0.667
Rout 4-4	59.2	27.66	455.7119	0.172	0.16	0.016	0.65
Rout 4-5	50.3	27.55	385.2561	0.142	0.158	0.027	0.67
Rout 4-6	57.5	28.47	455.5554	0.159	0.157	0.032	0.649
Rout 4-7	49.9	30.27	419.9918	0.144	0.134	0.018	0.704
Rout 4-8	55.9	29.71	462.1725	0.186	0.118	0.025	0.671
Rout 4-9	56.4	29.66	465.5975	0.175	0.155	0.035	0.633
Rout 4-10	56.6	29.84	469.9722	0.167	0.171	0.022	0.638
Average	55.08	29.127	445.9237	0.1624	0.1593	0.0244	0.6523
SD	3.66782	1.11296	27.12125	0.013993649	0.026854	0.00648	0.026205
COV	0.06659	0.03821	0.06082	0.086167792	0.168573	0.26574	0.040173

1.5 Mixed traffic corridor (1) measurements in Abu Dhabi

1.5.1 Airport Road (6.30-7.30 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Airport T(1) 6.30-7.30 Am (In) Bus	459.2	18.14	2314.085	0.201	0.204	0.2	0.392
Airport T(2) 6.30-7.30 Am (In) Bus	540.4	14.47	2172.951	0.193	0.202	0.309	0.295
Airport T(3) 6.30-7.30 Am (In) Bus	420.1	19.06	2224.248	0.206	0.131	0.187	0.474
Airport T(4) 6.30-7.30 Am (In) Bus	633.3	13.87	2440.676	0.1909	0.192	0.363	0.253
Airport T(5) 6.30-7.30 Am (In) Bus	616.5	15.91	2725.055	0.172	0.127	0.283	0.416
Airport T(6) 6.30-7.30 Am (In) Bus	501.2	16.104	2241.624	0.183	0.187	0.284	0.344
Airport T(7) 6.30-7.30 Am (In) Bus	651.7	14.26	2582.588	0.189	0.174	0.395	0.239
Airport T(8) 6.30-7.30 Am (In) Bus	474.9	15.52	2048.432	0.171	0.1606	0.35	0.317
Airport T(9) 6.30-7.30 Am (In) Bus	617.8	12.98	2227.738	0.188	0.184	0.336	0.29
Airport T(10) 6.30-7.30 Am (In) Bus	533.9	15.79	2341.723	0.1705	0.172	0.32	0.336
Airport T(1) 6.30-7.30 Am (Out) Bus	557.8	15.49	2400.433	0.193	0.189	0.266	0.35
Airport T(2) 6.30-7.30 Am (Out) Bus	427.6	19.73	2343.327	0.194	0.203	0.188	0.413
Airport T(3) 6.30-7.30 Am (Out) Bus	375.7	22.88	2388.603	0.186	0.146	0.207	0.459
Airport T(4) 6.30-7.30 Am (Out) Bus	384.1	20.88	2228.443	0.192	0.085	0.26	0.461
Airport T(5) 6.30-7.30 Am (Out) Bus	347.6	25.64	2476.108	0.203	0.193	0.147	0.455
Airport T(6) 6.30-7.30 Am (Out) Bus	422.3	19.25	2258.541	0.195	0.184	0.236	0.383
Airport T(7) 6.30-7.30 Am (Out) Bus	445.9	18.99	2352.419	0.1802	0.1807	0.327	0.311
Airport T(8) 6.30-7.30 Am (Out) Bus	426.4	19.41	2299.082	0.146	0.024	0.343	0.485
Airport T(9) 6.30-7.30 Am (Out) Bus	401.3	20.45	2280.08	0.19	0.163	0.272	0.374
Airport T(10) 6.30-7.30 Am (Out) Bus	439.3	16.35	1995.375	0.139	0.027	0.428	0.405
Average	483.9	17.7587	2317.076	0.18413	0.156415	0.2851	0.3726
SD	92.62	3.25017	166.0423	0.017303729	0.053724838	0.0752	0.074193
COV	0.191	0.18302	0.07166	0.093975612	0.34347625	0.2637	0.199124

1.5.2 Airport Road (11.00-12.00 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Airport T (1) 11.00-12.00 Am (In) Bus	309	25.76	2211.476	0.218	0.189	0.103	0.487
Airport T (2) 11.00-12.00 Am (In) Bus	434.7	19.27	2327.449	0.183	0.183	0.22	0.413
Airport T (3) 11.00-12.00 Am (In) Bus	380.6	20.91	2210.86	0.204	0.187	0.182	0.425
Airport T (4) 11.00-12.00 Am (In) Bus	484	17.37	2335.843	0.185	0.186	0.273	0.354
Airport T (5) 11.00-12.00 Am (In) Bus	586.5	13.02	2122.163	0.158	0.031	0.424	0.383
Airport T (6) 11.00-12.00 Am (In) Bus	332.6	24.25	2240.769	0.207	0.196	0.163	0.433
Airport T (7) 11.00-12.00 Am (In) Bus	502.8	16.91	2362.113	0.149	0.05	0.304	0.496
Airport T (8) 11.00-12.00 Am (In) Bus	420.1	19.85	2316.758	0.185	0.066	0.267	0.48
Airport T (9) 11.00-12.00 Am (In) Bus	456.1	16.12	2043.097	0.178	0.024	0.341	0.454
Airport T (10) 11.00-12.00 Am (In) Bus	467.8	17.81	2314.402	0.205	0.132	0.312	0.348
Airport T(1) 11.00-12.00 Am (Out) Bus	308.5	27.94	2394.333	0.194	0.176	0.107	0.521
Airport T(2) 11.00-12.00 Am (Out) Bus	374.2	23.57	2449.887	0.202	0.186	0.151	0.458
Airport T(3) 11.00-12.00 Am (Out) Bus	384.9	22.87	2445.548	0.206	0.189	0.158	0.445
Airport T(4) 11.00-12.00 Am (Out) Bus	336.3	24.93	2328.97	0.203	0.181	0.123	0.491
Airport T(5) 11.00-12.00 Am (Out) Bus	318.3	25.73	2275.228	0.202	0.017	0.215	0.564
Airport T(6) 11.00-12.00 Am (Out) Bus	340	25.93	2448.426	0.211	0.052	0.238	0.497
Airport T(7) 11.00-12.00 Am (Out) Bus	274.6	30.706	2342.001	0.208	0.033	0.104	0.653
Airport T(8) 11.00-12.00 Am (Out) Bus	331	25.31	2327.11	0.2002	0.096	0.204	0.498
Airport T(9) 11.00-12.00 Am (Out) Bus	306.1	26.82	2280.72	0.202	0.138	0.143	0.515
Airport T(10) 11.00-12.00 Am (Out) Bus	347.8	23.85	2303.897	0.195	0.139	0.168	0.497
Average	384.8	22.4463	2304.052	0.19476	0.12255	0.21	0.4706
SD	81.42	4.57941	103.0816	0.017405214	0.068192819	0.0879	0.070438
COV	0.212	0.20402	0.044739	0.089367498	0.556448949	0.4184	0.149677

1.5.3 Airport Road (6.30-7.30 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Airport T(1) 6.30-7.30 Am (In) Car	320	26.98	2398.678	0.217	0.192	0.215	0.374
Airport T(2) 6.30-7.30 Am (In) Car	269.9	32.62	2446.245	0.187	0.195	0.147	0.469
Airport T(3) 6.30-7.30 Am (In) Car	230	36.807	2351.533	0.206	0.153	0.17	0.469
Airport T(4) 6.30-7.30 Am (In) Car	385.9	24.11	2585.242	0.213	0.181	0.219	0.384
Airport T(5) 6.30-7.30 Am (In) Car	287.9	30.74	2458.873	0.194	0.173	0.221	0.409
Airport T(6) 6.30-7.30 Am (In) Car	235.4	33.99	2222.629	0.192	0.169	0.101	0.536
Airport T(7) 6.30-7.30 Am (In) Car	200.8	40.42	2254.74	0.205	0.174	0.102	0.517
Airport T(8) 6.30-7.30 Am (In) Car	196.7	43.76	2391.491	0.209	0.186	0.076	0.526
Airport T(9) 6.30-7.30 Am (In) Car	224.8	39.55	2470.989	0.205	0.166	0.149	0.477
Airport T(10) 6.30-7.30 Am (In) Car	175	47.303	2299.564	0.234	0.166	0.035	0.563
Airport T(1) 6.30-7.30 Am (Out) Car	185.4	46.39	2390.257	0.164	0.038	0.044	0.752
Airport T(2) 6.30-7.30 Am (Out) Car	218.1	38.62	2340.148	0.211	0.171	0.11	0.5
Airport T(3) 6.30-7.30 Am (Out) Car	180.6	45.15	2265.484	0.213	0.169	0.057	0.559
Airport T(4) 6.30-7.30 Am (Out) Car	226.7	38.04	2396.044	0.197	0.175	0.122	0.503
Airport T(5) 6.30-7.30 Am (Out) Car	118.7	44.12	1455.722	0.198	0.179	0.04	0.581
Airport T(6) 6.30-7.30 Am (Out) Car	233.3	36.97	2396.296	0.211	0.145	0.162	0.48
Airport T(7) 6.30-7.30 Am (Out) Car	32.5	50.81	458.9315	0.282	0.107	0	0.61
Airport T(8) 6.30-7.30 Am (Out) Car	177.5	48.71	2401.961	0.204	0.186	0.076	0.532
Airport T(9) 6.30-7.30 Am (Out) Car	181.7	48.32	2439.367	0.201	0.175	0.058	0.564
Airport T(10) 6.30-7.30 Am (Out) Car	165.1	51.19	2347.953	0.208	0.161	0.049	0.581
Average	212.3	40.23	2238.607	0.20755	0.16305	0.1077	0.5193
SD	73.06	7.8195	474.3167	0.022283992	0.035060061	0.0661	0.084785
COV	0.344	0.19437	0.21188	0.107366863	0.215026441	0.6144	0.163267

1.5.4 Airport Road (11.00-12.00 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Airport T(1) 11.00-12.00 Am (In) Car	181.2	49.12	2473.291	0.201	0.178	0.04	0.579
Airport T(2) 11.00-12.00 Am (In) Car	173.8	49.14	2372.593	0.21	0.178	0.064	0.546
Airport T(3) 11.00-12.00 Am (In) Car	203.2	42.65	2408.08	0.2001	0.171	0.095	0.532
Airport T(4) 11.00-12.00 Am (In) Car	188.5	44.89	2350.743	0.189	0.178	0.132	0.5
Airport T(5) 11.00-12.00 Am (In) Car	174.3	49.37	2391.396	0.194	0.186	0.029	0.588
Airport T(6) 11.00-12.00 Am (In) Car	234.3	36.18	2354.943	0.221	0.184	0.147	0.446
Airport T(7) 11.00-12.00 Am (In) Car	184.9	45.12	2317.6	0.194	0.141	0.075	0.588
Airport T(8) 11.00-12.00 Am (In) Car	201.3	43.95	2458.167	0.198	0.084	0.094	0.623
Airport T(9) 11.00-12.00 Am (In) Car	149.6	49.88	2073.563	0.203	0.149	0.022	0.624
Airport T(10) 11.00-12.00 Am (In) Car	192.4	45.79	2448.168	0.22	0.149	0.049	0.58
Airport T(1) 11.00-12.00 Am (Out) Car	31	45.901	394.6604	0.067	0.012	0	0.919
Airport T(2) 11.00-12.00 Am (Out) Car	240.2	35.04	2338.608	0.211	0.177	0.125	0.484
Airport T(3) 11.00-12.00 Am (Out) Car	124.6	23.29	805.8683	0.221	0.193	0.205	0.38
Airport T(4) 11.00-12.00 Am (Out) Car	152.5	33.66	1425.834	0.212	0.176	0.131	0.48
Airport T(5) 11.00-12.00 Am (Out) Car	97.2	23.65	638.1406	0.21	0.203	0.184	0.4
Airport T(6) 11.00-12.00 Am (Out) Car	103.1	24.89	713.5482	0.195	0.184	0.21	0.409
Airport T(7) 11.00-12.00 Am (Out) Car	236.9	35.61	2344.554	0.219	0.189	0.143	0.447
Airport T(8) 11.00-12.00 Am (Out) Car	252.5	34.84	2444.391	0.222	0.185	0.147	0.443
Airport T(9) 11.00-12.00 Am (Out) Car	239.8	36.01	2399.714	0.184	0.025	0.175	0.614
Airport T(10) 11.00-12.00 Am (Out) Car	201.2	39.95	2232.769	0.206	0.141	0.096	0.554
Average	178.1	39.4466	1969.332	0.198855	0.15415	0.1082	0.5368
SD	56.22	8.59365	722.4577	0.033069933	0.053338319	0.0618	0.11887
COV	0.316	0.21786	0.366854	0.166301745	0.346015695	0.5719	0.221443

1.6 Mixed traffic corridor (2) measurements in Abu Dhabi

1.6.1 Elektra Road (6.30-7.30 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Elektra T(1) 6.30-7.30 Am (In) Bus	283.9	22.81	1798.901	0.186	0.2003	0.151	0.461
Elektra T(2) 6.30-7.30 Am (In) Bus	312.1	20.92	1813.856	0.126	0.082	0.245	0.544
Elektra T(3) 6.30-7.30 Am (In) Bus	339.1	19.306	1818.499	0.195	0.201	0.148	0.454
Elektra T(4) 6.30-7.30 Am (In) Bus	269.7	23.94	1793.966	0.201	0.198	0.1	0.5
Elektra T(5) 6.30-7.30 Am (In) Bus	288.3	23.02	1844.233	0.191	0.201	0.14	0.467
Elektra T(6) 6.30-7.30 Am (In) Bus	334.7	18.76	1744.769	0.174	0.063	0.247	0.514
Elektra T(7) 6.30-7.30 Am (In) Bus	348.1	18.603	1798.918	0.197	0.205	0.193	0.403
Elektra T(8) 6.30-7.30 Am (In) Bus	339.7	19.78	1866.831	0.212	0.182	0.187	0.417
Elektra T(9) 6.30-7.30 Am (In) Bus	392.1	17.38	1893.246	0.134	0.059	0.355	0.449
Elektra T(10) 6.30-7.30 Am (In) Bus	295.2	22.46	1842.196	0.2008	0.2001	0.156	0.441
Elektra T(1) 6.30-7.30 Am (Out) Bus	420.5	16.54	1932.149	0.193	0.149	0.276	0.381
Elektra T(2) 6.30-7.30 Am (Out) Bus	434.5	14.73	1778.137	0.147	0.113	0.328	0.411
Elektra T(3) 6.30-7.30 Am (Out) Bus	386.9	17.89	1923.974	0.2	0.203	0.241	0.354
Elektra T(4) 6.30-7.30 Am (Out) Bus	517.9	14.19	2041.86	0.148	0.119	0.335	0.395
Elektra T(5) 6.30-7.30 Am (Out) Bus	396.5	16.67	1836.853	0.189	0.194	0.227	0.388
Elektra T(6) 6.30-7.30 Am (Out) Bus	380	17.1	1805.211	0.149	0.107	0.255	0.487
Elektra T(7) 6.30-7.30 Am (Out) Bus	401.6	16.47	1838.198	0.181	0.052	0.322	0.444
Elektra T(8) 6.30-7.30 Am (Out) Bus	397.9	16.28	1799.827	0.172	0.058	0.311	0.457
Elektra T(9) 6.30-7.30 Am (Out) Bus	377.2	17.301	1812.972	0.196	0.18	0.204	0.419
Elektra T(10) 6.30-7.30 Am (Out) Bus	368.7	15.98	1637.393	0.125	0.042	0.299	0.532
Average	364.23	18.507	1831.1	0.17584	0.14042	0.236	0.4459
SD	59.833	2.8369	80.27553	0.027492131	0.062740305	0.0747	0.05151
COV	0.1643	0.1533	0.04384	0.156347423	0.446804623	0.3166	0.11551

1.6.2 Elektra Road (11.00-12.00 am) (In and outbound) Bus

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Elektra T(1) 11.00-12.00 Am (In) Bus	322.5	18.98	1700.658	0.189	0.163	0.234	0.413
Elektra T(2) 11.00-12.00 Am (In) Bus	344.4	17.58	1681.647	0.196	0.198	0.226	0.377
Elektra T(3) 11.00-12.00 Am (In) Bus	309.5	16.12	1385.974	0.198	0.187	0.237	0.376
Elektra T(4) 11.00-12.00 Am (In) Bus	264.6	24.68	1814.472	0.186	0.155	0.184	0.473
Elektra T(5) 11.00-12.00 Am (In) Bus	241.5	21.72	1457.039	0.196	0.081	0.199	0.522
Elektra T(6) 11.00-12.00 Am (In) Bus	259.6	25.05	1807.293	0.216	0.145	0.148	0.49
Elektra T(7) 11.00-12.00 Am (In) Bus	326.7	18.03	1635.965	0.193	0.207	0.195	0.403
Elektra T(8) 11.00-12.00 Am (In) Bus	260.6	24.21	1752.4	0.222	0.186	0.119	0.472
Elektra T(9) 11.00-12.00 Am (In) Bus	309.9	20.36	1752.93	0.2	0.147	0.191	0.46
Elektra T(10) 11.00-12.00 Am (In) Bus	275.4	19.63	1502.112	0.163	0.179	0.259	0.397
Elektra T(1) 11.00-12.00 Am (Out) Bus	343.5	14.06	1341.882	0.135	0.052	0.36	0.451
Elektra T(2) 11.00-12.00 Am (Out) Bus	364.3	14.87	1505.529	0.178	0.126	0.301	0.393
Elektra T(3) 11.00-12.00 Am (Out) Bus	278.1	16.78	1296.529	0.202	0.184	0.19	0.422
Elektra T(4) 11.00-12.00 Am (Out) Bus	291.4	17.54	1420.033	0.18	0.02	0.262	0.527
Elektra T(5) 11.00-12.00 Am (Out) Bus	260.8	15.93	1154.074	0.145	0.033	0.277	0.543
Elektra T(6) 11.00-12.00 Am (Out) Bus	283.7	17.42	1373.326	0.11	0.035	0.298	0.555
Elektra T(7) 11.00-12.00 Am (Out) Bus	434.6	13.301	1605.208	0.158	0.04	0.387	0.412
Elektra T(8) 11.00-12.00 Am (Out) Bus	364.5	17.01	1722.482	0.163	0.067	0.282	0.486
Elektra T(9) 11.00-12.00 Am (Out) Bus	457.9	14.18	1803.886	0.166	0.139	0.315	0.377
Elektra T(10) 11.00-12.00 Am (Out) Bus	348.3	12.67	1226.019	0.109	0.038	0.424	0.427
Average	317.09	18.006	1546.973	0.17525	0.1191	0.2544	0.4488
SD	58.005	3.6802	207.7431	0.031679107	0.065596775	0.0786	0.05772
COV	0.1829	0.2044	0.13429	0.18076523	0.550770568	0.3091	0.1286

1.6.3 Elektra Road (6.30-7.30 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Elektra T(1) 6.30-7.30 Am (In) Car	183.4	35.85	1827.017	0.163	0.158	0.176	0.501
Elektra T(2) 6.30-7.30 Am (In) Car	211.1	29.06	1704.255	0.196	0.04	0.267	0.495
Elektra T(3) 6.30-7.30 Am (In) Car	226.9	29.59	1865.67	0.194	0.212	0.199	0.393
Elektra T(4) 6.30-7.30 Am (In) Car	204.5	30.71	1744.904	0.162	0.017	0.269	0.549
Elektra T(5) 6.30-7.30 Am (In) Car	173.4	32.61	1571.497	0.222	0.042	0.23	0.504
Elektra T(6) 6.30-7.30 Am (In) Car	257.2	25.64	1831.972	0.197	0.186	0.294	0.321
Elektra T(7) 6.30-7.30 Am (In) Car	200	30.08	1671.362	0.183	0.022	0.329	0.463
Elektra T(8) 6.30-7.30 Am (In) Car	236.5	28.04	1842.659	0.187	0.144	0.242	0.425
Elektra T(9) 6.30-7.30 Am (In) Car	191.5	35.24	1875.398	0.208	0.125	0.18	0.485
Elektra T(10) 6.30-7.30 Am (In) Car	212.4	28.705	1693.641	0.164	0.179	0.265	0.389
Elektra T(1) 6.30-7.30 Am (Out) Car	181.6	30.33	1530.738	0.193	0.023	0.265	0.518
Elektra T(2) 6.30-7.30 Am (Out) Car	209.8	30.105	1754.785	0.149	0.028	0.205	0.616
Elektra T(3) 6.30-7.30 Am (Out) Car	176.9	36.75	1806.904	0.217	0.018	0.166	0.598
Elektra T(4) 6.30-7.30 Am (Out) Car	200.3	32.55	1811.72	0.211	0.197	0.18	0.411
Elektra T(5) 6.30-7.30 Am (Out) Car	202	32.79	1840.897	0.164	0.065	0.237	0.532
Elektra T(6) 6.30-7.30 Am (Out) Car	178.1	35.21	1742.782	0.195	0.175	0.191	0.437
Elektra T(7) 6.30-7.30 Am (Out) Car	173.5	34.37	1656.898	0.194	0.037	0.211	0.556
Elektra T(8) 6.30-7.30 Am (Out) Car	158.4	39.99	1760.721	0.193	0.071	0.202	0.532
Elektra T(9) 6.30-7.30 Am (Out) Car	144.8	40.79	1641.269	0.191	0.042	0.151	0.614
Elektra T(10) 6.30-7.30 Am (Out) Car	138.6	42.65	1642.753	0.197	0.048	0.109	0.644
Average	193.04	33.053	1740.892	0.189	0.09145	0.2184	0.49915
SD	29.393	4.5342	99.3643	0.019617393	0.070916908	0.0533	0.08573
COV	0.1523	0.1372	0.057077	0.10379573	0.775471934	0.2438	0.17176

1.6.4 Elektra Road (11.00-12.00 am) (In and outbound) Car

The following table shows the results from this section:

The Routs	Time	Speed	Distance	Acceleration	Deceleration	Idling	Cruising
Elektra T(1) 11.00-12.00 Am (In) Car	241.5	27.209	1825.011	0.189	0.16	0.359	0.29
Elektra T(2) 11.00-12.00 Am (In) Car	244.8	24.91	1694.483	0.196	0.133	0.249	0.42
Elektra T(3) 11.00-12.00 Am (In) Car	179	37.44	1861.812	0.214	0.015	0.231	0.537
Elektra T(4) 11.00-12.00 Am (In) Car	228.7	29.33	1863.988	0.202	0.083	0.375	0.337
Elektra T(5) 11.00-12.00 Am (In) Car	110.2	58.12	1779.856	0.204	0.166	0.004	0.623
Elektra T(6) 11.00-12.00 Am (In) Car	207.4	31.56	1818.495	0.212	0.186	0.258	0.343
Elektra T(7) 11.00-12.00 Am (In) Car	194.3	33.05	1783.803	0.228	0.031	0.219	0.519
Elektra T(8) 11.00-12.00 Am (In) Car	206.2	32.49	1861.135	0.208	0.222	0.09	0.478
Elektra T(9) 11.00-12.00 Am (In) Car	215.2	27.03	1616.407	0.195	0.052	0.259	0.491
Elektra T(10) 11.00-12.00 Am (In) Car							
Elektra T(1) 11.00-12.00 Am (Out) Car	255.6	24.44	1735.338	0.105	0.049	0.355	0.489
Elektra T(2) 11.00-12.00 Am (Out) Car	237.1	23.33	1537.219	0.201	0.148	0.29	0.359
Elektra T(3) 11.00-12.00 Am (Out) Car	186.2	28.82	1490.932	0.131	0.029	0.305	0.532
Elektra T(4) 11.00-12.00 Am (Out) Car	172	28.55	1364.333	0.161	0.023	0.299	0.514
Elektra T(5) 11.00-12.00 Am (Out) Car	213.8	29.11	1729.034	0.213	0.14	0.324	0.321
Elektra T(6) 11.00-12.00 Am (Out) Car	168.6	36.42	1705.63	0.187	0.157	0.134	0.52
Elektra T(7) 11.00-12.00 Am (Out) Car	260	23.21	1676.054	0.209	0.207	0.282	0.3
Elektra T(8) 11.00-12.00 Am (Out) Car	197.6	26.14	1435.287	0.216	0.135	0.215	0.431
Elektra T(9) 11.00-12.00 Am (Out) Car	179.1	29.62	1474.547	0.206	0.211	0.171	0.411
Elektra T(10) 11.00-12.00 Am (Out) Car							
Average	205.41	30.599	1680.742	0.193166667	0.119277778	0.2455	0.43972
SD	37.22	7.9801	158.8432	0.031200019	0.070683059	0.0971	0.09704
COV	0.1812	0.2608	0.094508	0.161518648	0.592592014	0.3954	0.22069