DEVELOP DRIVING CYCLES TO DETERMINE FUEL CONSUMPTION AND FOR TRAFFIC ENGINEERING PURPOSES IN COLOMBO CITY

Uditha Nandun Galgamuwa

Index No: 138026C

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Department of Civil Engineering

University of Moratuwa

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DECLARATION

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ABSTRACT

Driving cycle can be considered as one of the useful methods of modelling traffic behaviour on road for many purposes such as traffic engineering, fuel economy and setting up emission standards. A driving cycle is a series of data points representing the speed of a vehicle versus time in a particular environment. There are hundreds of driving cycles developed all around the world and driving cycles are well established in US, Europe, Australia and in some of the Asian countries. Many driving cycles in those four regions were analysed to identify the best method for Sri Lanka.

Four steps have been identified for cycle construction and the best methods for Sri Lanka was selected after analysing the traffic behaviour of the places where the driving cycles were analysed in the comparison. For both traffic engineering purpose and estimation of emission inventories, the route selection method was done using daily traffic, origin/destination and trip generators and attractors. For the data collection, on-board measurement method was adopted after evaluating the advantages and disadvantages of the chase car method with the on board measurement method. A new approach was used for the data collection after dividing the selected routes and assigning them in to links and combined them using daily traffic proportions. Cycle construction methods were chosen according to the purpose of the cycle construction. Segment based cycle construction method was used to develop a driving cycle for traffic engineering purposes. For fuel economy and estimating emission inventories three methods were used. Micro trip-based cycle construction method was used when there are many "stop-go" conditions. Segment-based cycle construction method used where there are less or no stops between origin and destination (Expressways). Modal cycle construction method was used where there are many variations in driving behaviour (different magnitudes of accelerations and decelerations).

Ten parameters were identified for cycle evaluation and they vary according to the purpose of the cycle construction. Emission related traffic parameters were used to analyse the emission and fuel economy related driving cycles and hence the selected cycle will represent the actual emission or fuel consumption in considered region. Similarly, for the traffic engineering purpose the parameters related to traffic management were considered when evaluating the driving cycle for traffic engineering purpose.

Key Words: driving cycles, vehicle emission, fuel economy, traffic engineering.

DEDICATION

To my loving Parents and to the people supported in many ways to make this dream a reality.

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LIST OF ABBREVIATIONS

DMV	-	Department of Motor Vehicle
AADT	-	Average Annual Daily Traffic
DT	-	Daily Traffic
OD	-	Origin Destination
SAPD	-	Speed Acceleration Probability Distribution
SAFD	-	Speed Acceleration Frequency Distribution
LOS	-	Level of Service

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CHAPTER ONE

1. INTRODUCTION

A driving cycle is a series of data points representing the speed of a vehicle vs time in a specific road or a region (Tong and Hung, 2010). It is the key for transportation related decision making. For decades the researchers all around the world have developed different driving cycles with many attributes. Even though simple methodology has been used at the beginning of the development of the driving cycles in the past it has become complicated at present to capture actual driving behaviour in the area of concern. There are many complicated and advanced methods of developing driving cycles to represent the actual on-road driving pattern. Modern driving cycles have considered not only the traffic behaviour and the physical characteristics on the road but also some of them have considered the driver age groups and gender distribution.

Furthermore, driving cycles are used by many for different purposes such as tire manufactures to estimate their tyre performance, traffic engineers to make traffic related decisions, environmental scientists to setting up emission standards, and economists and other decision makers to estimate the fuel economy to conduct cost benefit analysis.

Driving cycles can mainly categorized as legislative and non-legislative according to the purpose of use. Driving cycles for emission purpose, traffic engineering purposes (Tong et al, 1999) and some of the driving cycles for fuel estimation can be considered as legislative driving cycles. Driving cycles for tyre performance, (Andre, 2004a; Barlows et al, 2009) engine performance and some of the driving cycles for fuel efficiency can be considered as non-legislative driving cycles.

Hence it is necessary to have a "Driving cycle" for a given country/region at least for the congested areas that need more attention to resolve traffic related problems, and for setting up fuel economy and emission standards.

1.1. Problem

Vehicle emission has become one of the major problems in Sri Lanka at present. Even though many attempts have been made to develop emission estimation models, still knowledge is lacking with respect to actual vehicle emissions. Many studies have been conducted to identify the parameters that affect vehicle emission. But Sri Lanka does not have methods of evaluating fuel performance in specific road or region which could be used for cost benefit appraisal of road developments and the majority of the traffic related decisions are made by the experience elsewhere. Therefore it is necessary to implement a method which could cater to all of the above requirements.

Driving cycle is one of the best solutions which could be used to address majority of the issues regarding emission standards, fuel economy and traffic related problems (Andre, 2004a; Barlows et al, 2009). However, no "Driving Cycle" has developed for Sri Lankan conditions and no accurate driving cycle available in the South Asian region. Even though USA, Australia, Hong Kong and many countries in Europe have developed advanced and highly reliable driving cycles for many purposes, Sri Lanka cannot use them directly in Sri Lankan condition, because the driving pattern, vehicle condition and road condition are different from those countries.

Therefore it is necessary to develop representative "Driving Cycles" for Sri Lankan condition to address the issues of emission-related problems, fuel economy as well as traffic related problems.

1.2. Objectives

1. To identify the suitable methods for data collection and cycle construction for emission purpose, fuel economy purpose and traffic engineering purposes.
2. To identify the representative route(s) for Colombo area to collect data for the purpose of fuel consumption and determine emission inventories.
3. To develop driving cycles for traffic engineering, emission inventory and fuel economy purposes.
4. Identify the parameters which can be used to assess the constructed driving cycles

CHAPTER TWO

2. Literature Review

2.1. Introduction

Driving cycle can be defined as a series of data points representing speed vs time (Tong et al, 2010), speed and gear selection as a function of time (Barlows et al, 2009), speed vs distance (Nesamani et al, 2011) or time vs gradient (Han et al,2012) in a specific region or a part of a road segment. Driving cycles are used for many purposes such as traffic engineering (Tong et al, 1999) estimation of emission inventories (Barlows et al, 2009; Andre, 2004) and fuel economy (Tamsanya et al, 2009). Among those purposes most frequently driving cycles have been used to estimate emission inventories and fuel economy by doing a chassis dynamometer test (Kumar et al, 2011: Andre et al,2009: Hung,2005).

There are two different methods to estimate the emission inventories and fuel consumption namely travel based models and fuel based models (Xiao, 2012). Driving cycles are under travel based models. Also there are many fuel-based models around the world which are used to estimate fuel consumption and emission inventories such as traffic flow models and traffic emission models (Pandian et al, 2009), instantaneous emission models (Zamboni et al, 2011: Joumard et al,1999), average speed emission models (Joumard et al,1999) and using independent driving pattern factors (Ericsson, 2001). These models use empirical co-relations where the results are obtained from many samples and then develop a co-relation for further prediction.

If the modal is for estimation of fuel consumption or emission inventories first the fuel consumption and emissions are measured using on board method and then develop a relationship to explain the behaviour which has been measured or monitored. Nevertheless the driving cycles use a different method. First it identifies the smallest component which affects the fuel consumption and emission and then develop a model using those small segments. First the spatial and temporal characteristics of the route or a region were identified and then collect data and using data driving pattern is illustrated. Technology and the capital needed is very much low compared to the other available methods. Therefore the driving cycle will be a better solution for a Sri Lanka to estimate fuel consumption and emission inventories.

Driving Cycles have been developed since early 70s and it can be broadly divided in to two segments namely Transient Driving Cycles, which are developed using on road data (Ex-selecting a trip which best fits to the data population collected in the region) and the "Modal" or "Polygonal" Cycles, which are developed by composing the collected data using selected mechanism (Tong, 2010) (Ex- use markove chain modal to develop a best fit modal to collected data population). FTP 72 and FTP 75 (Federal Test Procedure) developed in USA can be considered as first driving cycles developed in the world (Hung et al, 2007) and afterwards many driving cycles have been developed and the representativeness of the actual driving pattern has been increased along with its accuracy to predict on road behaviour.

Air pollution has become a major concern around the world and the vehicle emission is one of the major sources of air pollution (TZIRAKIS, 2006).Within the last decade (from 2003 to 2013) the number of vehicles have been doubled in Sri Lanka (Department of Motor Vehicle, 2013 June) hence the congestion in urban and sub urban areas have been increased. Due to above reasons government of Sri Lanka is more concerned about the vehicular emission levels in urban and sub urban areas. The current emission standards available are out dated and to adopt European emission standards and updating emission inventories driving cycle has to be used. The problem is that there is no proper driving cycle developed for Sri Lankan condition and the readily available driving cycle elsewhere that can be directly used due to the differences in driving conditions and spatial and temporal driving characteristics. Therefore, it is necessary to develop a driving cycle for Sri Lanka which will represent the actual on road characteristics. Those characteristics can be categorized in to two segments. Those are parameters for traffic characteristics on the road and parameters for the fuel consumption and the emission on the road.

Parameters which affect traffic characteristics on the road are

- Traffic flow characteristics .(Tong and Hung 2010: Barrios, 2012)
  - Number of signalized un signalized inter sections
  - Traffic growth
  - Vehicle mix
  - Average trip length
- Weather condition (Ericsson, 2000)
- Spatial and temporal characteristic .(Tong and Hung 2010: Barrios, 2012)
  - Land use pattern
- Characteristics of the driver
  - Gender
  - Age
  - Discipline

Parameters which affect the fuel consumption and the emission on the road are

- Physical characteristic of the vehicle (Ericsson, 2000; Nesamani et al., 2007)
  - Vehicle type
  - Condition of the vehicle
  - Age of the vehicle
- Temperature (cold start or hot drive) (Nagpure, 2011: Weilenmann, 2013)
- Spatial and Temporal characteristic (Bishop, 2012: China, 2012)
  - Time of the day
  - Road condition
    - Road roughness
    - Topography
    - Number of lanes
    - elevation

To come up with an appropriate driving cycle model for Sri Lanka it is necessary to identify the methods used by other regions for developing driving cycles and from the literature four broad regions have being identified namely US, Europe, Australia and Asia where in most countries driving cycles have been developed intensively around thirty to forty years and few countries such as India, Philippine and Vietnam were started developing driving cycles in recent past. According to Hung (2007) and Gamalath (2012) four major steps for developing driving cycles can be identified namely

- Route Selection
- Data Collection
- Cycle Construction
- Cycle Evaluation

2.2. Route Selection

A driving cycle for an area must be determined from the traffic data along the travelling routes of those vehicles. The number of such possible road links would be enormous and it is impossible to conduct actual measurements of the vehicle speed characteristics on all the road links. For that, representative test routes are necessary to reflect typical traffic conditions (Tamsanya, 2008).

To select the traveling routes that can best represent the actual traffic, the real situations occur along each route in the area considered must be known and these routes would cover the driving conditions from one end of the particular area to the other end. Usually these routes are determined with the due considerations of the following criteria

1. Travel activity patterns

Day to day travel activity pattern of the interested area should be studied and based on the origin destination travel pattern, the typical trip length of the travellers can be determined. By performing a questionnaires survey, an appropriate test route length is determined (Tong and Hung 2010: Barrios, 2012).

2. Traffic flow characteristics

Traffic flow characteristics have a major influence on emission levels of a particular area. Therefore traffic flow characteristics of the routes to be selected should reflect the traffic flow of the whole area of interest. Some of the traffic flow characteristics which considered are (Tong and Hung 2010: Barrios, 2012);

- Average speed
- Traffic density at a particular time interval
- Vehicle distribution etc.

3. Road type

Type of the road is to be considered as the emission levels depend on the level of service of a particular road. Therefore to select the representative test routes, road type of the each road route should be taken into account. The selected test route types should represent the combination of the road types in the interested area (Tong and Hung 2010: Barrios, 2012).

4. Land use

Land use also has an influence on traffic conditions of a particular area. Traffic congestion in week days is high if there are more commercial activities and if there are more recreational activities there is a possibility of having traffic congestions in weekends. OD pattern also depend on the land use of a particular area (Tong and Hung 2010: Barrios, 2012).

5. Topography

Driving conditions are different from mountainous terrain to rolling terrain. Therefore it is important to consider the topography of the area of concern and select routes (Tong and Hung 2010: Barrios, 2012).

6. Population density

Population density of an area has an influence on Origin Destination (OD) pattern of that particular area. Also it contributes for traffic density and traffic flow characteristics of the area of concern. Although this is not directly connected with the vehicle emission levels, it is to be considered when selecting the test routes.

When selecting the routes, parameters considered are given a weightage and according to the weightage the routes are selected. The weightage given for each factor is subjective. It is based on the purpose of driving cycle development and also the researcher (Tong and Hung 2010).

When developing driving cycle for emission purposes or to estimate fuel consumption, the gradient of the selected route(s) should be considered. The reason is that the fuel consumption varies significantly due to road grade on the micro segment scale (Bishop, 2012). Further, when developing a driving cycle for a region it is necessary to consider the weather condition on each route selected because the driving pattern will vary due to weather condition (Ericsson, 2000), Micro texture of the routes (China, 2012) and altitude and temperature as well (Nagpure, 2011). Whatever the parameters considered, representing the actual driving behaviour in a region travel activity patterns (particularly O-D pattern), quantitative traffic related indicators and a systematic method/ Mechanism should be used when selecting routes (Tong and Hung, 2010). Below mentioned are the methods used by the countries of the four regions and it can be clearly seen that some of the countries have adopted advanced methods when selecting routes and some of them have not.

When developing the Hong Kong driving cycle the route selection was mainly based on experience and knowledge of the local traffic conditions and for the route selection from the defined origin/destination pair and then the highest overall Average Annual Daily Traffic (AADT) was combined and the AADT was considered as a reference in determining the traffic density. Then the routes which are used frequently have been selected and the selected route assumed to represent the actual driving pattern in that area. Also the routes were selected for each time of the day which will represent the majority of vehicles using AADT (Hung, 2007).

In Hanoi, Vietnam driving cycles for motorcycles and light duty vehicles, the routes were selected considering travel activity patterns (O-D travel patterns) and traffic flow characteristics. But in Hanoi there are no any readily available historical traffic data. Therefore onsite observation and the knowledge and the experience of the researcher is used when selecting routes together with four aspects namely road type criteria (highways, main roads, collecting streets, and internal streets), route length criteria (according to the results from the survey the mean trip length was calculated), traffic volume criteria (most heavily trafficked roadways were identified) and land use criteria (according to the questionnaire survey) (Tong, 2011)

Similarly, for Colombo (Sri Lanka), for preliminary route selection for driving cycle was mainly based on the experience and local knowledge about the traffic behaviour in Colombo area and some parameters for the data collection such as Daily Traffic (DT), land use pattern, population density and road classification (Gamalath,2012). However, only one, continuous road was selected to represent the area to develop a driving cycle due to the prevailing constraints such as lack of historical traffic data as in Hanoi, Vietnam time and resources. The major drawback of this method for Colombo condition is that it is difficult to identify the exact routes simply based on the experience since the traffic behaviour is indistinguishable in this region.

The route selection of Bangkok driving cycle is based on the traffic flow data and the travel speed. Using traffic flow data traffic flow model is developed and hence determines the travel speed along each section of major road routes considered. Then establish the distribution of travel speeds of vehicles in the area. Secondly, few major roads were selected which are closely matched to that of the whole major roads previously established. Selected roads are evaluated using some statistical parameters such as variances and mean of target parameters with collected population data. These few major roads are therefore expected to cover all driving speed patterns occurring in the city and has been used as representative routes for conducting real driving tests to collect the driving characteristics (Tamsanya, 2006).

ARTHEMIS driving cycle is developed for European region and therefore it represent actual driving pattern of European region. Here, the routes have been selected randomly from France, UK and Germany. Unlike in Hong Kong, the drivers have given the freedom to follow the traffic flow (Andre, 2004).

Comparing the different route selection methods used around the world methods used by Australia for Melbourne, Perth and Sydney are much more advanced than many cycles developed. Many parameters have considered for route selection such as land use, road type, driving condition and availability of public transportation (Hung, 2007). In Sydney cycle routes were selected according to road classification and the traffic density in the areas of highest emissions. Routes were thus concentrated in this region so as the measure driving patterns where emissions are expected to be highest. Also time period of data collection were selected by conducting an O-D survey (Kent, 1978).

In Perth driving cycle, six regions have been identified for the study and thirteen routes have been selected based on best available data which describes the traffic behaviour and the actual road condition of the routes in Perth city such as Vehicle kilometre travelled (VKT) and traffic volumes. This attempt is to cover the important routes in Perth city and to consider high and low volume roads. But the routes selected form this method is not meant to represent the actual route which might take by the motorist but to provide rational sampling framework to represent the driving pattern in selected six regions. In Melbourne cycle ten routes within 8 km radius of the Melbourne central business city have been selected which covers central business district, arterial and freeway conditions (Kenworthy, 1986).

One of the best logical route selection methods was used by Australian Composite Urban Emission Driving Cycle (ACUEDC). They have collected data from Brisbane, Sydney, Melbourne, Adelaide and Perth metropolitan areas. Routes have been selected according to the travel time available to provide a representative sample of routes and travel environments within the metropolitan area and are based on the arterial road network (Zito, 2005). Though it is one of the best methods there are several limitations to adopt that method for countries where there is a lack of readily available traffic data.

2.3. Data Collection

For any research, data collection plays a vital role because the quality of the output is directly influenced by the reliability, representativeness, homogeneousness and consistency of the data which have collected. To collect on road data literature states three methods namely

- Chase car method
- On board measurement method (Tong et al., 2000)
- Hybrid method of those two (Tong et al., 2010)

Other than that when selecting vehicles for either type of data collection method it is better to consider the engine capacity of the vehicle which is used because the driving Patten could be changed due to engine capacity of the vehicle (Andre´, 2006).

2.3.1. Chase car method

Chase car method is one of the most popular methods of data collection for construction of driving cycles. An instrumented vehicle is used to collect data which can measure second by second speed data of a chased car in a predetermined route(s) within area of concern. (Niemeier, 1999) There are some different types of instruments mainly used for such type of data collection. (Hung et al., 2007) Such as

- GPS
- Microwave
- Tachometer (Infra-red sensor)

In this method a vehicle is targeted and chased in the traffic stream. When selecting target vehicle, attention should be given on the colour of the chased car. It has to be a bright colour to clearly identify the particular vehicle in the traffic mix. If not the targeted vehicle might be lost because of the traffic congestion of the road. The data (speed) is recorded at the desired interval (distance/time). Most practiced method in driving cycle construction is recoding per second data (Hung et al., 2005).

The chase car method has been adopted for LA92 and LA01 driving cycles developed in USA and the driving data consisted of 102 runs and 100,709 seconds, and data was collected in greater metropolitan Los Angeles area (Lina, 2002). The method cannot be adopted for the countries where there is aggressive driving behaviour. If so the data set will not represent the actual driving pattern. Not only in USA but also some other countries have adopted this method for their driving cycles such as

- Perth cycle
- Melbourne peak cycle
- Sydney cycle
- Edinburgh cycle
- Pune, India (Hung et al., 2007)

Although the method is used in all over the world, some advantages and disadvantages of adopting a chase car method as a data collection method can be identified.

One of the advantages of the chase car method is that it requires lesser resources comparing to on board measurement method. Hence, it is cost effective as compared to on-board measurement method. Due to cost consideration the chase car method has been used as the data collection method to developed Manila driving cycle (Sigua, 1997). Also it is more representative of actual driving behaviour. Here, the driver doesn't know that he is being monitored by a third party. If he knows the driver will behave differently, rather than normal behaviour in that traffic stream. Then it will not give an actual driving pattern of the vehicle.

Further, the route is not pre-determined one. Therefore the data gathered represent the actual driving condition of the vehicle which represents a typical driving pattern. This is very important as the representativeness of the data that is collected is important (Tong et al., 2010).

Some of the disadvantages of the chase car method is that it is a complicated method because, some times the speed of the car is not equal to the chased car and the acceleration deceleration are can also be different from the targeted vehicle due to the behaviour of other drivers (when using GPS and Tachometer). The driver in the chasing vehicle may get confused by the behaviour of the targeted vehicle as well as by the other vehicles on the road.

It may be difficult to follow some drivers due to their driving pattern such as speed, acceleration and attitudes toward the road signs and rules. Then it becomes difficult to collect data from such vehicles and need to repeat it for another vehicle. Then it becomes more time consuming and costly. (Tong et al., 2010)

In addition, some drawbacks can be seen in the way the researchers have used the chase car method to develop driving cycles. Especially in Pune, India, they have identified five major roads (total length of 55km) in Pune to collect data to develop a driving cycle by considering the AADT and data was collected during peak hours (Kamble, 2009). Since they have collect data in five major roads in peak hours, it will overestimate the fuel consumption as well as the emission inventories in that area. Therefore, as done in Edinburg cycle (Booth, 2001) data should be collected at both peak and off peak hours.

2.3.2. On board measurement method

On board measurement is another method used to collect data for developing driving cycle. Here, instruments are installed on selected vehicles and let the vehicles travel along the traffic stream. Then second by second speed data is recorded as they travel along the predetermined routes.

When implementing on board measurement method major emphasis has to be given for the route selection method. It is possible to select routes or drivers randomly and collect data, but it could end up with biased data set. If the method of random route selection is adapted the database has to be increased as in ARTHEMIS cycle. In the ARTEMIS driving cycle the data is collected using on board measurement method and 77 vehicles were used to collect real world data. To increase the accuracy of the data sample 2,200 hours of data was recorded, where the data set was collected covering 2,000 days (5.5 years), 10,300 trips, 88,000 km and the vehicle usage and operating conditions were reported (Andre, 2004) as same as in Australian Composite Urban Emissions Drive Cycle (CUEDC). In CUEDC sample size of 431.4 hours has been used to increase the accuracy in considerable amount (Zito, 2005)

Tong (1999) developed a driving cycle for Hong Kong using on board measurement method and the equipment used for data collection was different. Data acquisition was done using optical sensor pointing to the axle of the test vehicle. The rotation of the wheel is measured by the infrared photoelectric senor and pulse convertor. Then the speed data were collected in the micro-computer. To capture the critical scenario data was collected during peak period ranging from 8:00 a.m. to 11:00 a.m. But for Hong Kong driving cycle developed by Hung (2007), data was collected using on board measurement method combined with chase car method using GPS loggers. 29 hours of data were collected with the chase car method and 5.6 hours of data was collected using on board measurement method along nine selected representative routes during the morning peak hours. A total of 74 trips of speed data were recorded along nine different routes, in which 44 were urban speed profiles, four were sub-urban speed profiles, and 26 were highway speed profiles.

Also for the Bangkok driving cycle and driving cycles for motorcycles and light-duty vehicles in Vietnam data was collected during peak hours. In Bangkok driving cycle data was collected using a real time logging system equipped on a selected vehicle traveling along the routes under actual traffic and the speed time data was collected during morning peak period between 7:00 a.m. to 9:00 a.m. to capture the driving condition which has the largest impact on exhaust emission and fuel consumption. The data collection for each route was carried out for two weeks. (Tamsanya, 2006) and when developing driving cycles for motorcycles and light-duty vehicles in Vietnam data was collected using on board measurement method and totally 60 trips where 40 trips were representing motorcycle profiles and 20 trips were Light Duty Vehicle Profile (Tong, 2011).

As in chase car method there are some advantages and disadvantages of adopting on board measurement method. One of the advantages of adopting on board measurement method is that it is possible to get the direct measurement of speed data as the chase and the chased vehicle is the same.

When the chased car method is used, chaser attempt to drive similar to the chased vehicle but the speeds accelerations and decelerations might be different from the chased vehicle because of the delay due to drivers' response time. However having on board measurement method as data collection method it is possible to overcome delay due to driver's response time (Tong et al., 2010).

There are some disadvantages of having on board measurement as a data collection method. The route is pre-determined and then the driving pattern is different from the actual driving pattern. Because the data is taken from the whole trip between two destinations which the driving cycles need to be constructed, but in the real situation every vehicle would not travel directly between those two locations and depending on their destination driving pattern may change (Tong et al., 2000).

In On board method driver knows that he has been monitored during whole period of his drive. Then the driving pattern can be different from that of the actual driving pattern. Then the data might not represent the actual behaviour of the corresponding road. In this method the equipment is attached directly to the vehicle and therefore it only measure and collect data of the corresponding vehicle. (However in chase car method we can measure and collect data of any vehicle because the equipment is mounted in another vehicle). Therefore, on board method requires a large sample size of vehicles to get data from different types of vehicles. Further, cost wise the on board measurement method is may be expensive because it is necessary to give each and every vehicle an instrument to collect data.

2.4. Cycle Construction

Methods of driving cycle construction varies with the intended use of the driving cycle, such as emission inventory development or traffic engineering purposes. Each method has inherited features that serve the intended purpose. As an example when developing driving cycles for emission and fuel estimation it is necessary to consider the cold start if it is a country which has lower ambient temperature. The reason is that the temperature will be the major parameter in the terms of emission and fuel (Weilenmann et al, 2013: Demuynck, 2012). If it is for the traffic engineering purpose the cycle should represent the actual point on the road for given speed or time. Hence a driving cycle developed for emission study purpose may not suit for traffic engineering purposes. The Driving cycles developed in early stages in US, FTP72 and FTP75, which can be considered as the first driving cycles in the world, the researchers have developed the driving cycle by selecting the whole trip which best fits the overall survey data. However, due to subsequent improvements in cycle construction leads to four major driving cycle construction methods namely

- Micro-trip based cycle construction
- Segment based cycle construction
- Pattern classification cycle construction
- Modal cycle construction (Dai et al. 2008)

2.4.1. Micro-trip based cycle construction

Micro trip based cycle construction can be defined as driving activity between adjacent stops, including leading period of idle (Dia 2008 cited in Austin et al 1993) and this can be considered as the frequently used cycle construction method around the world.

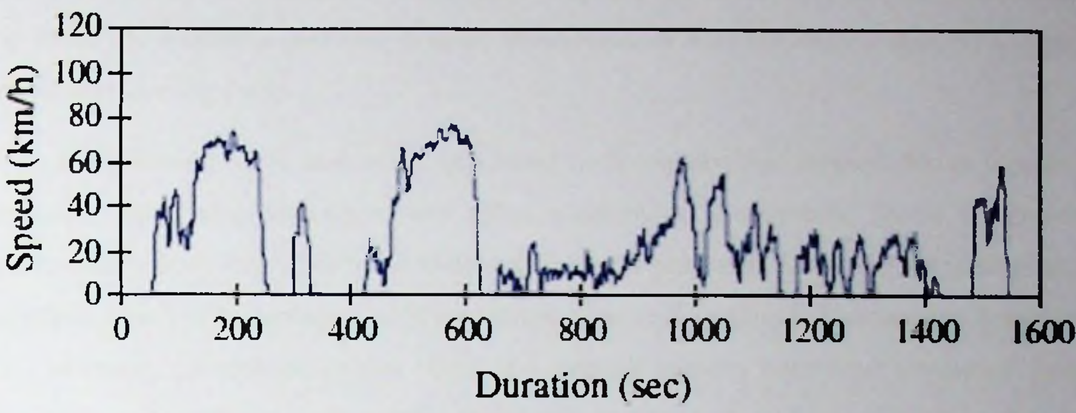


Figure 1: Graphical representation of a driving cycle

In micro-trip cycle construction travel data is divided in to micro trips and assign them to bins according to their mean velocity and then the driving cycle is constructed by chaining micro trips with the goal that the cycle closely matches the observed data. According to Dia (2008) cited Austin et al (1993) there are two methods of selecting micro trips for the cycle

- Random selection
- Best incremental method

In addition Hybrid of these two methods can also be used

In micro trip based cycle construction the major limitation is that it is not possible to differentiate micro trip by various types of driving conditions such as roadway type or Level of Service (LOS). Therefore it is limited to developing cycles designed to represent a single type of trip or cycles designed to replicate region-wide driving conditions (Dia et al, 2008 cited Andre 2004) It is well known that more fuel needs to be provided to the vehicle during the ''stop-go'' periods. Traffic signals and congestion conditions cause these ''stop-go'' driving patterns and lead to higher fuel consumption (Chen, 2007). Since micro trip based cycle construction covers each stop-go condition it will be a better solution for emission purpose and fuel estimation purpose.

LA92 (California driving cycle, USA) was developed using micro trip based cycle construction method and quasi random method for micro trip selection (Lin, 2002). Colombo preliminary driving cycle is constructed using micro trip based cycle construction method. Twelve parameters have being used such as proportions of idling, cruising, acceleration and deceleration and maximums and minimums of speed, running speed and average speeds

(Gamalath, 2012). Therefore it is important to identify the countries which have used micro trip based cycle construction and compare those methods with the method used by Colombo preliminary driving cycle.

Pune, India driving cycle used micro trip based cycle construction method. Micro trips were generated using data population and speed acceleration distribution. Speed acceleration matrices have been created for each micro trip that was generated. Using those matrices target parameters such as percentage time in acceleration, percentage time in deceleration, percentage time in cruise, percentage time in idling and average velocity have been generated. Speed acceleration distribution and speed acceleration matrices have been created to the data population and using those matrixes target parameters were generated for the population as same as for the micro trips. When selecting micro trips for the candidate cycle target parameters, micro trips have been matched with the population target parameters and the tolerance limit was given as 5% for lower limit and 15% for upper limit (Kamble, 2009).

In Hong Kong, Positive Kinetic Energy (PKE) has been used as a target parameter which represents the actual emission on the road. Even though the Manila driving cycle has used micro trip cycle construction, micro trips are selected using statistical methods such as Fourier series, time series analysis, curve fitting techniques using polynomial functions (Sigua, 1997). Bangkok driving cycle has been developed using micro trip based cycle construction and micro trips are selected randomly from the database (Tamsanya, 2006).

2.4.2. Segment-based cycle construction

The main constrain in micro trip method is that it cannot be used in an area or a road where there are less or no stops between origin and destination (Ex- Expressways). By eliminating the main constrain in micro trip based method, Segment based cycle construction method has been developed. In this method, instead of micro trip a 'trip segment' is used to construct the driving cycle. A trip 'segment' is obtained by partitioning vehicle speed-time profiles using changes in roadway type or level of service, in addition to stops. (Carlson and Austin 1997)

Unlike in micro trip based cycle construction trip segments are selected and linked by using both random and best-incremental logics in Segment based cycle construction method. In addition to stops, changes in roadway type or LOS are considered when selecting a trip "segment" (Dia et al, 2008 cited Carlson and Austin 1997). Therefore the trip segments can represent the actual traffic condition as well as the physical characteristics of the road and LOS as well. A micro trip usually starts and ends at zero speed, but a trip segment can starts and ends at any speed. Therefore, unlike in micro trip based method, chaining of segments requires certain constraints on speed and acceleration between two connecting segments respectively of previous and succeeding trip segments.

Number of candidate driving cycles can be constructed as previous and the best cycle can be selected using two primary parameters;

I. The sum of difference in Speed Acceleration Frequency Distribution (SAFD) between test cycle and the target population
II. The percentage amount of operation occurring in high power mode (Carlson and Austin 1997).

This method is suitable for a driving cycle for traffic engineering purposes. But when chaining the trip segment it is necessary to consider speed and acceleration between two connecting seconds respectively of previous and succeeding micro-trips because unlike in micro trip based cycle construction trip segment can start and end at any speed. Even though this method is used for a traffic engineering purpose it is less suitable for emission purpose (Dia et al, 2008). Segment based cycle construction has been used to develop Composite Urban Emissions Drive Cycle (CUEDC) in Australia. They have identified the road categories as congested, residential/minor, and arterial and freeway/highway and each micro trip was assigned one of four road flow categories based on the average speed of the micro trip and the proportion of idle time in the micro trip. Then they have developed the driving cycle using target parameters as same as micro trip based cycle construction method (Zito, 2005).

2.4.3. Cycle construction with pattern classification

Under this method of cycle construction, 'kinematic sequences' are classified into heterogeneous classes using statistical methods. This approach uses succession probabilities to estimate and consider the likelihood that one class of activity precedes or follows a different activity class. Driving cycles are constructed by re-connecting kinematic sequences randomly selected from each of the activity classes in accordance with the probability and chronology of kinematic sequences (Andre et al. 1995).

This method has been widely applied in constructing European driving cycles (Andre 1996; Andre et al. 1995; Andre and Rapone, 2008). For the construction of European cycles, kinematic sequences have been described by twenty parameters. Some of the are variables shown below (based on most commonly used parameters used around the world);

- Duration
- Idle time
- Distance throughout the sequence
- The means and maximums
- 20% and 80% percentiles of driving modes
- Instantaneous speed/ acceleration
- Distance between two accelerations etc.

Principle component analysis is applied to these 20 variables, followed by cluster analysis on the kinematic sequences. Four distinctive classes have then identified, respectively representing congested and free flow urban traffic, extra urban and motorway driving conditions.

Then, a trip is viewed as a series of kinematic sequences. All observed trips are classified based on the frequency of sequences in each kinematic sequence class and the number of transitions between two classes of kinematic sequences. Three major types of trips are identified, namely urban trips, road trips and motorway trips.

To avoid bias due to the varying duration of sequences between two stops, speed time traces are segmented into sequences of homogeneous size rather than partitioned by stops. Correspondence analysis using chi-squared distance and cluster analysis are applied to classify the sequences into twelve driving conditions. Urban, rural road and motorway cycles are developed based on the observed composition of driving conditions (Andre 1996; Andre et al. 1995; Andre and Rapone, 2008).

Many of European driving cycles have been developed using this method or partially using this method. ARTEMIS driving cycle was developed using this method and kinetic sequence have classified in to heterogeneous classes using 12 parameters. Succession probabilities were used to estimate and consider the likelihood that one class of activity precedes or follows a different activity class. Driving cycles are constructed by re-connecting kinematic sequences randomly selected from each of the activity classes in accordance with the probability and chronology of kinematic sequences. Likewise four cycles were constructed for urban, rural and motor way, namely ARTHEMIS Urban cycle, Artemis Road cycle, Artemis Motorway cycle, Artemis Motorway130 cycle. (Andre, 2004).

Though it is one of the major methods of constructing driving cycles around the world there are some limitations of adopting the method. Kinematic sequences are not directly related to emissions and potentially not the best units to be used in defining emission related driving activity. The classification of sequences is based on the chi-square distance of speed acceleration joint distribution. Although such classification differentiated the kinematic driving activity, it does not necessarily differentiate emissions associated with these activities. (Dia et al, 2008)

2.4.4. Modal cycle construction

In modal cycle construction actual driving patterns are divided in to acceleration, deceleration, cruising and idling. To construct the driving cycles "Markov Chain" theory is used. Hence, assume that the likelihood of particular modal event is depends only on the pervious modal event (Lin et al,2003) There are four basic steps for constructing driving cycle using modal cycle construction method (Dia et al 2008 cited Lin and Niemeier 2002) as follows:

1. Actual driving data is partitioned into snippets of various durations based on acceleration using maximum likelihood estimation (MLE) clustering method.
2. The snippets are classified into different modal bins, again using the MLE clustering method. This time, the clustering variables include average, minimum, and maximum speeds and acceleration rates.
3. Creates a transition matrix that contains the succession probabilities between different modes.
4. Cycle is constructed as a Markov chain; to add one additional snippet, the next modal bin is predicted based on the modal nature of the current snippet and the transition matrix.

According to the Lin and Niemeir (2003) one of the major limitations is that still the number of cycles needed to represent the emission related driving activity are not well studied.

To develop LA01 (California, USA) cycle, a similar method used for European cycles have been used. Maximum Likelihood estimation is used to partitioned route based instantaneous speed into snippets of varies durations and intensities. Then the data is clustered in to modal bins and a modal event bin, labelled by speed and acceleration. All the modal event bins combined define a set of states and form the state space of a Markov process. Target parameters such as average speed, maximum speed, maximum acceleration, and idle time (%) and road power along with speed acceleration frequency distribution (SAFD) of the candidate cycle is compared with the population parameters and select a data set which can develop a driving cycle which represent the actual driving pattern in the region. The selection process is repeated until the desired cycle length is achieved (Lin, 2002). In micro trip based cycle construction, four kinetic modes, starting form idling, acceleration, cruise, deceleration and idling (the four kinetic modes between two adjacent stops include leading idling) are considered as a one trip. But in the modal cycle construction method, micro trip is further segmented in to four kinetic modes as mentioned above. Then develop a Markov model to predict next mode of kinetic sequence and combine those mode to construct ta driving cycle using probability of occurrence of those modes. Then the developed cycle will more accurately represent the actual driving on the road. Also the Markov chain has been used to develop driving cycles for Bay Area, Sacramento and Stanislaus, California (Lin, 2003) as well as for Hefei, China for their driving cycles (Shi, 2011)

As Lin and Niemeier (2003) suggested there few limitations such as

- The snippets are connecting arbitrarily
- Cycles are constructed for a specific facility and LOS
- Number of cycles needed to represent the emission related driving activity are not well studied
-

2.4.5. Markov Chain model

Among many other methods available for selecting next mode of occurrence in a traffic flow such as Knight's tour Markov chain modal is the one which was used by many researchers around the world.

Markov Chain is a theory to predict next event using the current event mode. It is very useful for the synthesis of driving cycle using Modal cycle construction (Shi, 2011: Bishop, 2012).

Let S= $\{s_0, s_1, \ldots s_N\}$ be a set of states and $q_1, q_2, \ldots q_{k-1}, q_k \ldots$ be a series of points in time where each $q_i \epsilon S$

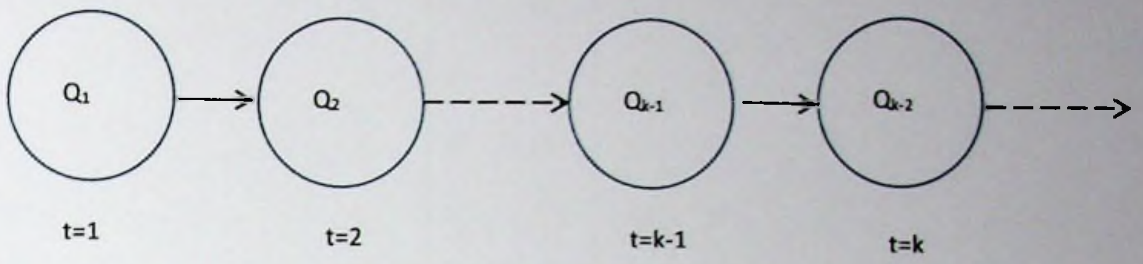


Figure 2: Markov chain process

There the assumption is made that the current state depends only on the immediately preceding state.

$$P\,(q_k=s_i \,/\, q_{k-1}, \ldots q_1, q_0) = P(q_k=s_i \,/\, q_{k-1}) \qquad \text{Equation 1}$$

Then the states are define with the probabilities. For an example if the speed time trip was taken, for major states can be identified namely idle (S_i), acceleration (S_a), deceleration (S_d) and cruising (S_c). And the probabilities can be calculated using the data sample.

Assume the initial state of probabilities as below

$P(S_i) = 0.2$

$P(S_a) = 0.2$

$P(S_d) = 0.2$

$P(S_c) = 0.4$

And then the transition probability matrix is constructed using those states as given in table 1

Table 1: Transition probability matrix for state changes

	S_i	S_a	S_d	S_c
S_i	0	B	0	0
S_a	0	C	F	I
S_d	A	D	G	J
S_c	0	E	H	0

(English capital letters are used as constant values in the matrix)

Also for the construction purpose states have been defined as follow (Shi, 2011)

1. Idle mode: the speed is 0, but the engine is still at work ,
2. Acceleration mode: vehicle speed change value is positive, and acceleration absolute value is greater than 0.1 m/s^2,
3. Deceleration mode: vehicle speed change value is negative, and acceleration absolute value is greater than 0.1 m/s^2 absolute;
4. Cruise mode: the acceleration absolute value is less than (or equal to) 0.1 m/s^2 and speed is not 0.

Also for more accuracy those states have divided in to some more segments using average speeds of the snippets. As an example

Table 2: Defining states for transition probability matrix

	$a \leq -0.8$	$-0.8 < a \leq -0.1$	$-0.1 < a \leq 0.1$	$0.1 < a \leq 0.8$	$a > 0.8$
$V_1 \leq v_m < V_2$	State 1	State 2	State 3	State 4	State 5
$V_2 \leq v_m < V_3$	State 6	State 7	State 8	State 9	State 10
$V_3 \leq v_m < V_4$	State 11	State 12	State 13	State 14	State 15
$v_m > V_4$	State 16	State 17	State 18	State 19	State 20

(V_1,V_2,V_3 and V_4 are constants)

Using transition probability matrix, the next state of driving can be predicted. Also using above matrix it is possible to construct a driving cycle which is best represent the actual driving modes on road.

2.5. Cycle Assessment

Cycle assessment is one of the major steps in developing driving cycles because the assessment criteria assure that the cycle truly represent the actual on road driving in that particular area or region. Many countries have used different methods and parameters to assess their developed cycles. In common, many countries used Performance value (PV). First using the population target parameters has been calculated and then the parameters are calculated for the candidate driving cycles. Then the deviation or the percent deviation is calculated between target parameters and the parameters calculated for the candidate driving cycles. Finally the summation of the absolute values of the deviations is taken by multiplying each absolute deviation by a weightage. This weightage is given according to the relevance of those parameters to the purpose of the driving cycle (weather it is for emission purpose or traffic engineering purpose)

At the early stage of developing driving cycle, in FTP72 and FTP75 number of stops per distance, average speed, and maximum speed have been used to assess the cycles. Since then various parameters have been used to assess the driving cycles. It can be seen that the driving cycles developed in recent past have used some common parameters such as maximums and minimums, time proportions, averages, standard deviations, percentiles and some specific parameters for emission such as Root mean square acceleration (RMS), Vehicle Power (P) and Positive acceleration Kinetic Energy (PKE).

2.5.1. Maxima and Minima

Hefei, China driving cycle has used maximum acceleration and minimum acceleration for the assessment criteria (Shi, 2011). Maximum speed driving cycle for intra city busses in Chennai has used maximum deceleration (Nesamani, 2011) and the LA01 driving cycle has used maximum acceleration rate (Lina, 2002). Also other than these maximums and minimums some of the driving cycles such as LA01, Manila driving cycle has used maximum and minimum speeds for the cycle assessment (Sigua, 1997).

2.5.2. Percentages

LA01(Lina, 2002) and Manila (Sigua, 1997) driving cycles used percentage idle time and Bangkok driving cycle used percentages of number of micro trips and their time spans of the selected micro trip (Tamsanya, 2006). But the commonly used percentages or the proportions for the assessment criteria are idle time proportion, acceleration time proportion, deceleration time proportion, cruise time proportion which were used for driving cycles in Hefei; China (Shi, 2011), Hanoi; Vietnam (Tong, 2011), Hong Kong (Tong, 1999: Hung,2007), Pune; India (Kamble, 2009) and Bangkok (Tamsanya, 2006 and 2009). Moreover in driving cycle for intra city busses in Chennai percentage of time spent in creeping mode also be considered other than previously mentioned four parameters (Nesamani, 2011).

2.5.3. Means and Averages

Most frequently used averages are average speed, average running, average acceleration and average deceleration and they have been used to assess Hefei driving cycle: China (except average deceleration) (Shi, 2011), Hanoi driving cycle :Vietnam (Tong, 2011), Bangkok driving cycle (Tamsanya, 2006), Manila driving cycle :Philippine (Sigua, 1997) , driving cycle for intra city busses in Chennai: India (Nesamani, 2011).

Other than that mean length of a driving period, average number of acceleration deceleration changes within one driving period also used for some driving cycles such as Hanoi driving cycle and average acceleration/deceleration rate for LA01 (Lina, 2002).

2.5.4. Standard deviations and percentiles

Hefei driving cycle has used standard deviations such as speed standard deviation and acceleration standard deviation (Shi, 2011) and LA01 has used percentiles such as speed at the 95th percentile, acceleration/deceleration rate at the 95th percentile (Lina, 2002).

2.5.5. Specific Parameters

Not only statistical parameters but also some parameters derived from speed, time and acceleration deceleration changes have used to assess candidate cycles such as average road power by Hefei (Shi, 2011) and LA01 cycles (Lina, 2002), Root mean square acceleration (RMS) by Hanoi driving cycle (Tong, 2011) and Positive acceleration kinetic energy (PKE) by Hanoi (Tong, 2011), Bangkok (Tamsanya, 2006) and Hong Kong (Tong, 1999: Hung, 2007) driving cycles.

Most of the driving cycles developed around the world have used different types of parameters to assess the developed driving cycle but most of the cycles have used ten to thirteen parameters or less. But the Australian Composite Urban Driving Cycle (CUEDC) have used 46 parameters (Zito, 2005).

There six parameters represent the proportion time spent in mode such as proportion time idle, proportion time acceleration from idle, proportion time deceleration to idle, proportion time inter-acceleration, proportion time inter-deceleration, proportion time cruise. Instead of average values CUEDC has used the median values such as median idle time, median time acceleration from idle, median time deceleration to idle, median time inter-acceleration, median time inter-deceleration, median time cruise to avoid the effects of outlier data sets and then the standard deviation has been calculated for each parameter to understand the variation form the population CUEDC has used some parameters to represent the median magnitude of acceleration from idle, deceleration to idle, inter-acceleration, inter- deceleration, cruise along with their standard deviation. Also in CUEDC median value of trip distance, total trip time, average trip speed, idles, trip PKE, max speed trip, trip non idle speed, max trip acceleration and min trip deceleration with their standard deviation with population.

After assessing the candidate driving cycle using above parameters candidate driving cycle(s) is selected which has minimum PV and if there are more than one candidate cycle where the PV are approximately close then the SAPD/SAFD is used for further assessment.

2.5.6. SAPD or SAFD

Speed Acceleration Probability Distribution (SAPD) or Speed Acceleration Frequency Distribution (SAFD) is one of the common ways of assessing candidate driving cycles. There acceleration vs speeds vs probability is plotted in a 3D graph. For that speed are segmented in 5 km/h and acceleration in 1 km/h/s (Lyon et al, 1990)

Some driving cycles have used SAPD or SAFD for the selection of driving pattern to construct their driving cycle. In LA92 and LA01 SAFD was used to match the target parameters. By looking at the population SAFD the micro trip was selected for the cycle construction (Lina, 2002).

However in most cases such as in Hefei; China (Shi, 2011), Hanoi; Vietnam (Tong, 2011), Sydney (Kent, 1978), Istanbul, driving cycle for intra city busses in Chennai; India (Nesamani, 2011). Manila; Philippine (Sigua, 1997), Hong Kong (Tong, 1999: Hung,2007) and ARTEMIS driving cycles(Andre,2004) SAPD/SAFD is used to assess the candidate driving cycle with the population statistics. First SAPD/SAFD is created to whole population and then construct SAPD/SAFD for each candidate cycles. The most representative driving cycle was determined by the smallest sum square difference (SSD) between the SAPD/SAFD of the candidate cycle and the overall SAPD/SAFD.

Table 3: Traffic behaviour in different regions

Region		Name of the Cycle	Parameters				
			Average speed (km/h)	Average running speed (km/h)	PKE(m/s²)	RMS (m/s²)	%idle
US (Barlow,2009)		IM240	47.3	47.51	4.733	.178	.42
		FTP72	31.6	36.6	4.307	.2	13.81
		FTP75	34.2	39.21	4.197	.19	12.86
		LA92	39.6	45.22	5.409	.217	12.33
		NYK composite	14.1	18.97	3.434	1.4	25.85
Europe (Tong,1999: Barlow,2009)		ARTEMIS mw150	99.6	100.35	2.955	.092	.75
		ARTEMIS rural	57.5	58.39	4.007	.138	1.48
		ARTEMIS urban	17.7	22.29	7.137	.294	20.75
		ECE	18.7	27.1	.578	.77	30.8
Asia	Hong Kong(Tong,1999; Hung,2007)	HK sub urban	43	45	.4	.7	4.5
		HK highway	41	46	.2	.5	8.2
		HK urban	25.7	30.8	.4	.7	17
		HK1	18.12	24.33	.368	.714	25.59
	Sri Lanka (Gamalath,2012)	Colombo Driving cycle	21.95	Max speed 65	1.196	.625	11.83
	India (Nesamani,2011)	Chennai intra bus Driving cycle	14	21.8	.34	-	32.3
Australia	Population Parameters (Zito, 2005)	Freeway	40.71-57.35	46.2-58.89	.328-.504	-	11.3-14.1
		Arterial	29.78-34.93	33.34-37.05	.465-.524	-	21.5-26.1
		Residential	23.29	27.74	.608	-	28
	Kenworthy,1986	Perth	43.1	45-57	.42	.82	9.6
	Tong, 1999	Sydney	33.6	-	.52	.79	18.2

(Barlows, 2009)

2.6. Comparison of the Traffic Behaviour

Before taking any decision of adopting one or many methods to construct and assess a driving cycle it is important to identify the traffic condition of the area where the driving cycle has to be developed. Sometimes some construction methodology, assessment parameters are suitable for the traffic conditions of those countries but will not suit for the Sri Lankan condition. Traffic behaviour can be approximately represent using average speed, average running speed, Positive Kinetic Energy(PKE), Root Mean Square acceleration(RMS) and idle time proportion.

Average speed, average running speed and idle time proportion represent the Level of Service (LOS) in the area of concern. If the average speed, average running speed and low idle time proportion it can be assume that the area has low level of service and if the idle time proportion is relatively high then it can be assumed that the area has a lower level of service and more stop go conditions. Wise versa if the area of concern has higher average speed, high running speed and low idle proportion it can be assume that the area has higher LOS.

On the other hand PKE and RMS values give the idea about the driving pattern and how aggressive the drivers are. PKE and RMS can mathematically expressed using following equations

$$PKE = \frac{1}{dist} \sum_{i=2}^{n} \{v_i^2 - v_{i-1}^2 \ (where\ v_i > v_{i-1}) \qquad Else\ 0 \qquad \text{Equation 2}$$

$$RMS = \frac{\sum a^2}{Total\ time\ of\ acceleration} \qquad \text{Equation 3}$$

It can be seen that if the PKE and the RMS values are higher, then more aggressive the driver is.

According to Table 3 it can be seen that the average speeds are relatively low and medium in US city areas. Since FTP72 and FTP75 are quite old, NYK composite cycle and IM240 and LA92 can be considered as the current situation of traffic behaviour in US. It can be seen that the average speeds and idle time proportions of Los Angeles are relatively medium and around 40 km/h and 12% consecutively where New York City has a lower value of average speed around 14 km/h. But all together PKE values are higher than Australian and Asian regions and the drivers are much aggressive than those regions. Considering the idle time proportion and average speed LOS can be relatively medium except New York. In New York LOS is much lower than in other places which is considered above.

In Europe average speeds of the motorway and rural roads are high and the idle time proportions are very much low. Therefore it can be predicted that the LOS is high in those roads. Also the PKE values are much higher as in US roads and it can be assume that the aggressive driving behaviour of the drivers in those roads. In contrast, the average speeds of the urban roads are very much lower and the idle time proportions are around 20 to 30% and therefore it can be assumed as lower LOS in those roads in urban areas. Also the PKE values are much lower than the motor way and rural roads and it implies the soft and smooth driving behaviour of the drivers in those roads.

In Asia most of the cases which have been considered except Hong Kong sub urban and highway the average speed are relatively high idle times are around 11% to 30% and it can be considered as the low LOS in those roads and since it can be seen that the PKE values are lower except Sri Lanka it can be predicted as a smooth driving pattern on those roads. In Sri Lanka though the LOS is low the driving pattern is not very much smooth as in other Asian countries.

Australian arterial roads, residential roads and Sydney shows moderate average speed with higher idle time around 20% to 30%. It implies the low LOS in those roads and more stop go conditions. In freeway and Perth city average speeds are relatively moderate and the idle time proportion is low and the OS in those roads can be assumed as moderate. But in all the road the PKE value is relatively low and it can be assume the smooth driving pattern in those roads.

2.7. Applicability for Sri Lankan context

Route selection for the driving cycle has to done properly because the accuracy of the entire driving cycle is based on the representativeness of the selected routes. It is not advisable for select routes randomly as did in ARTHEMIS driving cycle or some cycles in Hong Kong and it is not possible for Sri Lanka to rely on many traffic related parameters and data base since Sri Lanka does not have such a data base as ACUEDC, Australia did or there aren't fully developed Origin Destination (OD) surveys, travel time and Average Annual Daily Traffic (AADT) for each and every area as used in later Hong driving cycles of in Bangkok cycle. And it is difficult and might be erroneous to select roads by expert judgment as did in early Colombo driving cycle. Therefore it is necessary to find out a method for the route selection using available resources and using some methods which are less costly and less time consuming.

Data collection has to be planned properly before starting the work. Because if the wrong method is selected for the data collection it will end up with a frailer or will provide a partial or not completed data set. Chase car method and on board measurement methods are commonly used methods around the world and they have their own advantages as well as dis advantages. Normally in congested area and where the driving pattern are not even such as in Colombo, Sri Lanka it is difficult to rely on chase car method. But since the cost is one of major consideration in the research it is not possible to totally rely on on-board measurement method.

When selecting cycle construction method it is necessary to consider the purpose of the driving cycle as well as the traffic behaviour which has been analysed in to some extend in Table 3. The reason is that in a free way or a rural area there will be low idle proportion and few stop go condition. Then the micro trip method will be not applicable for such a situation. Similarly if the number of acceleration deceleration changes are less, then it is not applicable to adopt modal cycle construction method. If it is a freeway or a road where the average speeds are high and the idle time proportion is less and there are few acceleration deceleration changes then segment base cycle construction method will be better. The advantages and disadvantages of using each cycle construction methods are mentioned in respective sessions along with the limitations.

Many parameters have been used for the cycle assessment criteria and many countries have used ten to thirteen parameters which describe the acceleration, deceleration, speed, time proportions a dynamic of the vehicle and some of the cycles such as ACUEDC has used more than forty parameters for the evaluation criteria. Also many countries have use SAPD or SAFD as a target parameter for cycle construction specially using modal cycle construction method and others have use those parameter to evaluate the candidate cycles with population.

CHAPTER THREE

3. Methodology

3.1. Introduction

Literature review was carried out to collect data about existing methods of emission and fuel modelling along with methods of traffic management system and the different approaches to driving cycle construction. From the previous studies four steps have been identified namely route selection, data collection, cycle construction and cycle assessment. From the literature survey the different method used around the world is to be identified and select one or many methods for develop a driving Cycle for Sri Lankan condition after evaluating the traffic behaviour and road condition in those countries.

3.2. Methodology Flow Chart

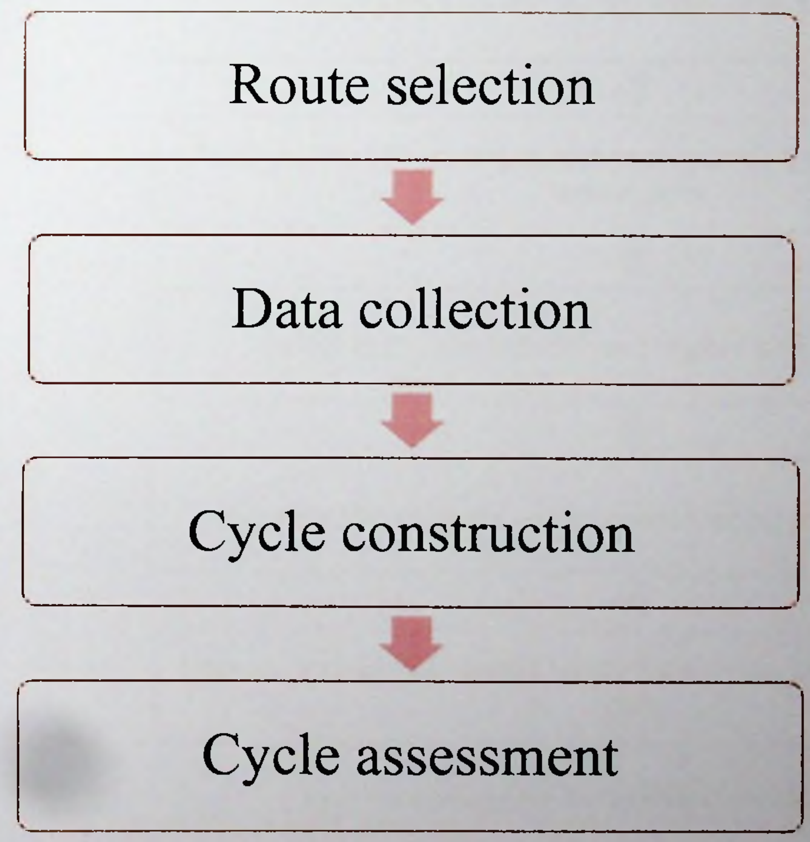


Figure 3: Methodology flow chart to construct a driving cycle

3.3. Route selection

Route selection is one of the major components related to the reliability and the representativeness of the driving cycle. Many countries have adopted different methods for route selection. Considering data available in Colombo city route selection is in two steps.

1. Route selection for intercity trips
2. Route selection for intra city trips

The methodology flow charts for route selections are shown in figure 4 and figure 5.

3.3.1. Route Selection for Intercity Trips

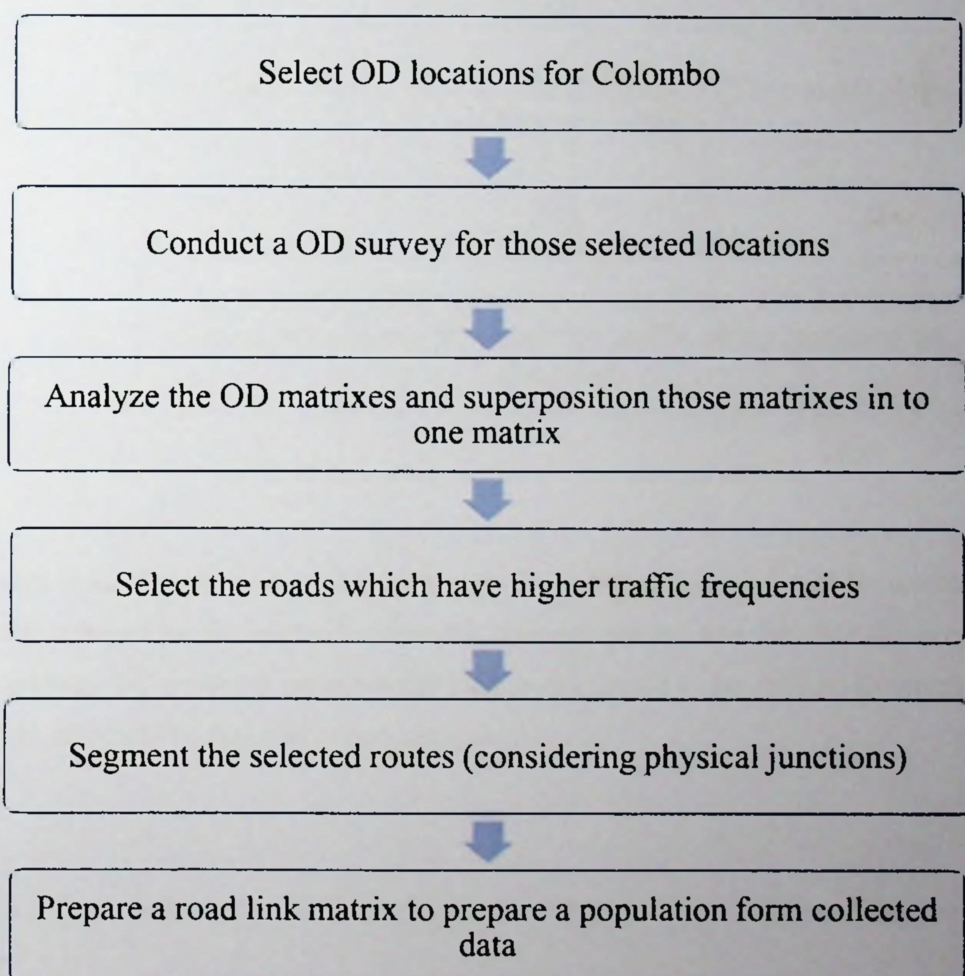


Figure 4: Methodology flow chart for intercity route selection

3.3.2. Route Selection for Intra city Trips

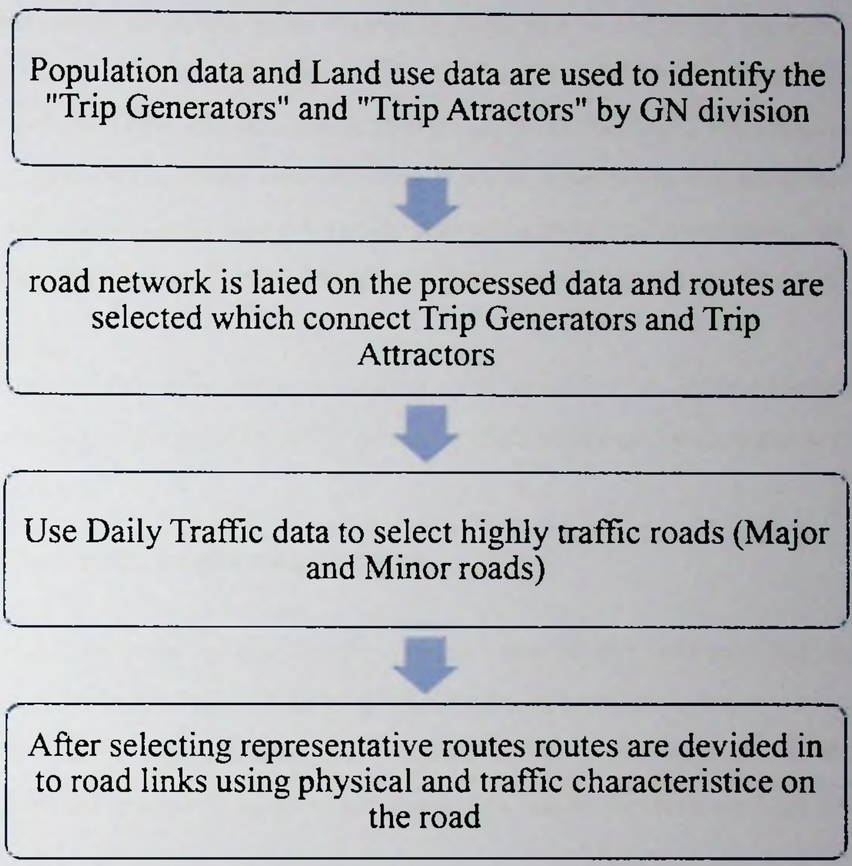


Figure 5: Methodology flow chart for intra city route selection

After selecting routes for inter-city and intra city roads were superimposed and the resultant road network is taken as the selected routes for data collection. And for data collection superimposed route link matrix is prepared and then proportionate to the daily traffic number of trips will be selected (As describe in data collection)

3.4. Data collection

Data collection is done using on board measurement method due to available resources, complexity of the traffic behaviour and time considerations. Five GPS equipment (BT-Q1300ST) were used to collect data and data is recorded in one second interval. Furthermore data is collected using pre-selected routes and collected in peaks. Inter peaks and off peaks. Number of data sets required from each time were calculated using daily traffic variation. Also number of data set required to synthesize the population is determined by the available MCC.

3.5. Cycle construction

Cycle construction is one of the major steps in driving cycle construction. Proper method should be selected according to the purpose of the driving cycle and to capture each mode of driving in the area of concern.

3.5.1. Driving Cycle for Traffic Engineering Purpose

Out of the four methods discussed in the literature review one of the best methods for developing driving cycles for traffic engineering purpose is Segment based cycle construction. There the micro trips are partitioned considering road conditions and traffic behaviour of the road. The micro trips from the same road segment are grouped in one bin as shown in figure 6.

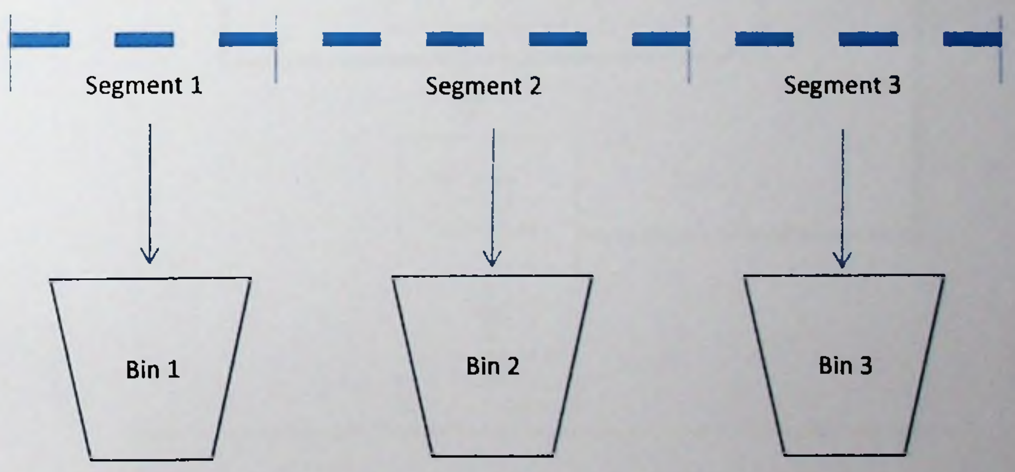


Figure 6: Method of assigning on road data in to bins for traffic engineering purpose

After grouped micro trips in to bins, they are further divided in to 5km/h interval groups according to their average speed. Then the trips are selected using random and best increment method to construct driving cycle. Driving cycle is constructed according to the actual length of the road (Speed vs Length).

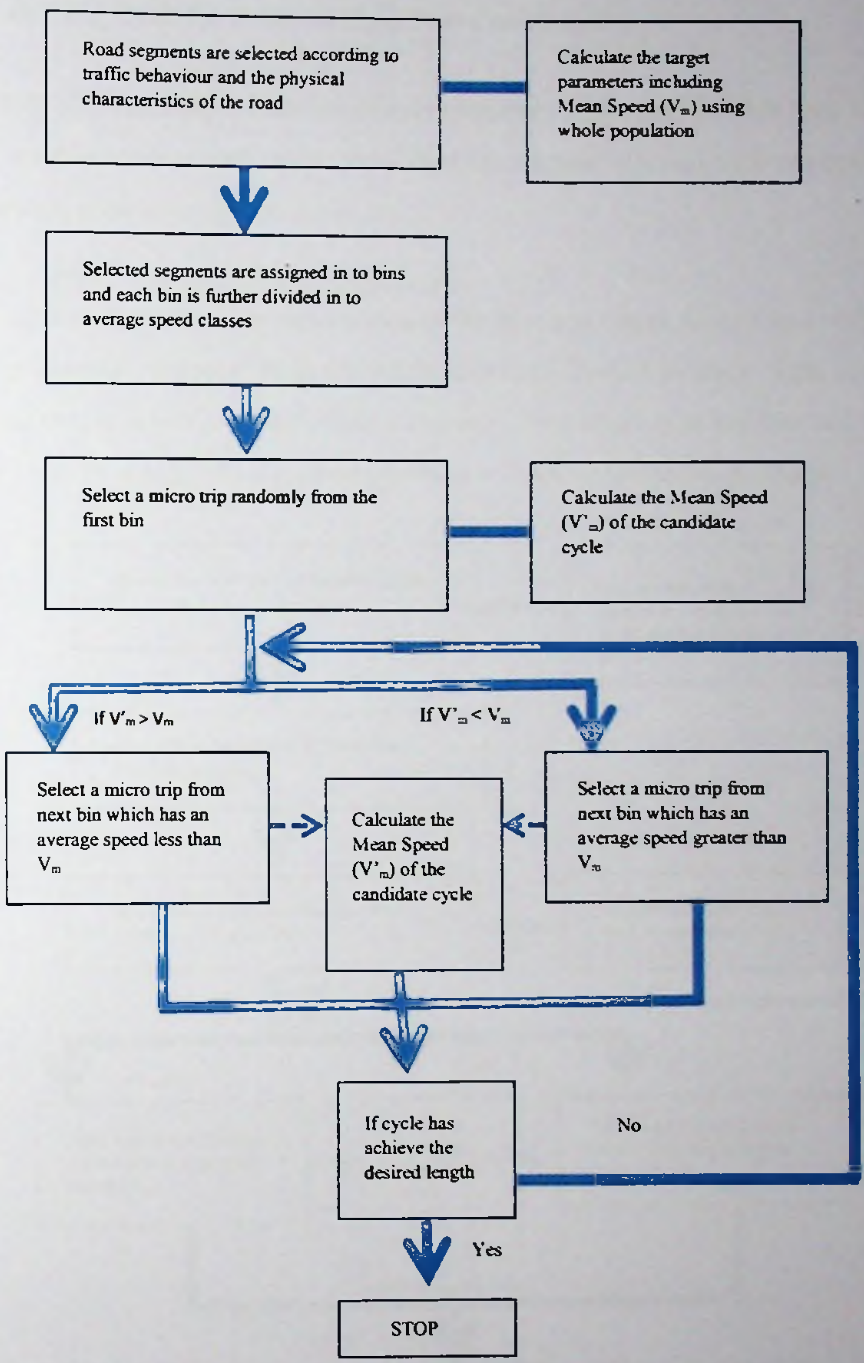


Figure 7: Methodology flow chart for developing driving cycle for traffic engineering purpose

3.5.2. Driving Cycle for Emission and Fuel Consumption

To estimate fuel consumption and emission inventories following methods have been identified for the construction methods and each method have limitations and different applications such as highways, normal congested roads etc.

3.5.2.1. Micro trip based cycle construction

Micro trip based cycle construction is one of the best and easier method to construct a driving cycle for emission purpose. First the whole trip(s) is divided to micro trips and assign them according to their average speeds (Speed classes). Then micro trips are selected to develop the driving cycle by using hybrid method (random and best incremental methods)

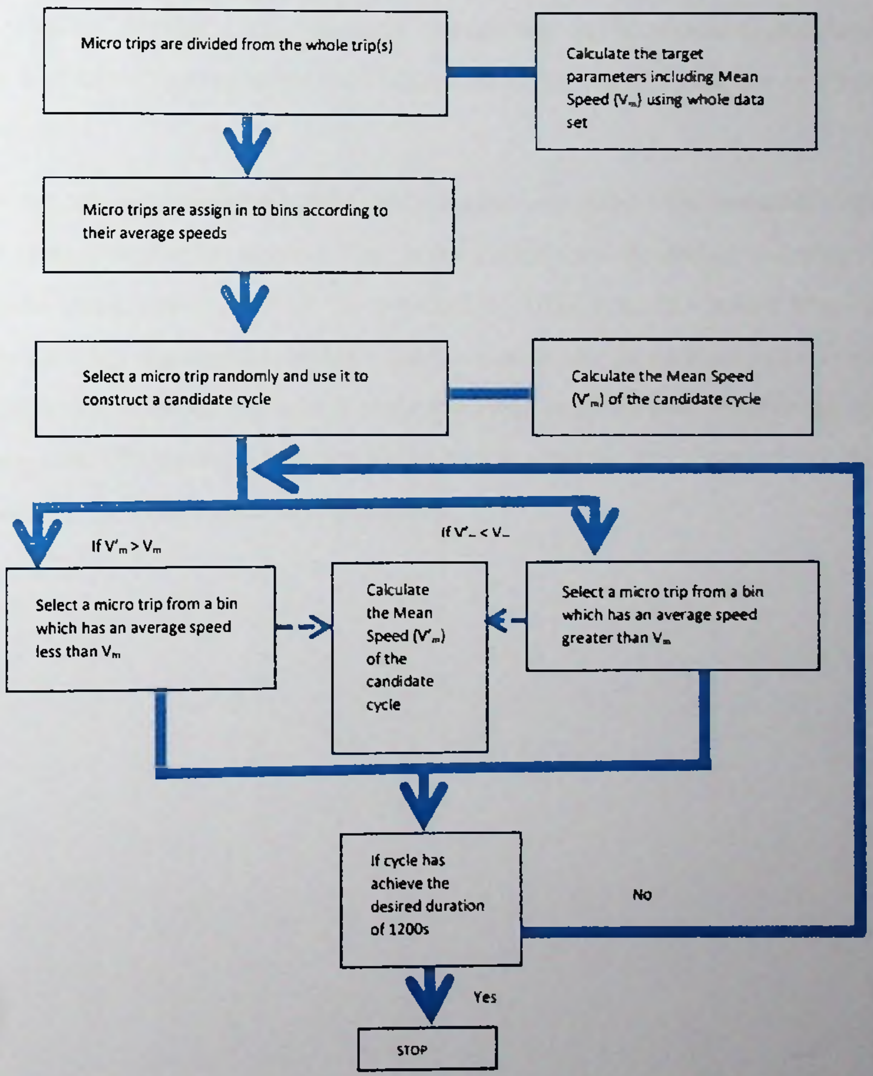


Figure 8: Methodology for develop driving cycle using micro trip based cycle construction

3.5.2.2. Segment based cycle construction

Segment based cycle construction method is one of the best method of constructing driving cycles for Highways or for an area or a road where there are less stops. (If there are less stops it is difficult to divide them in to micro trips and even it is possible the length of the micro trip is much higher compared to the length of the driving cycle and it will lead in to erroneous results)

In the segment based method the construction part is the same as in the micro trip based cycle construction but there are some restriction when dividing the micro trips and when chaining them in to a candidate cycle.

First the trips are divided in to segments considering traffic characteristics and the road conditions and then those segments are assigned in to bins considering the averages speed of those segments.

Trip segments are selected using hybrid method (random and best incremental) as did in micro trip based cycle construction method. Then trip segments are chained considering the average speed of the candidate cycle and the population. Unlike in the micro trip based cycle construction the trip segment can be start and finished at any speed therefore it is necessary to consider the speed between end speed of the previous segment and the starting speed of the selected segment. 5% variation between above mention speeds was accepted and the segments which have fulfilled above criteria was selected.

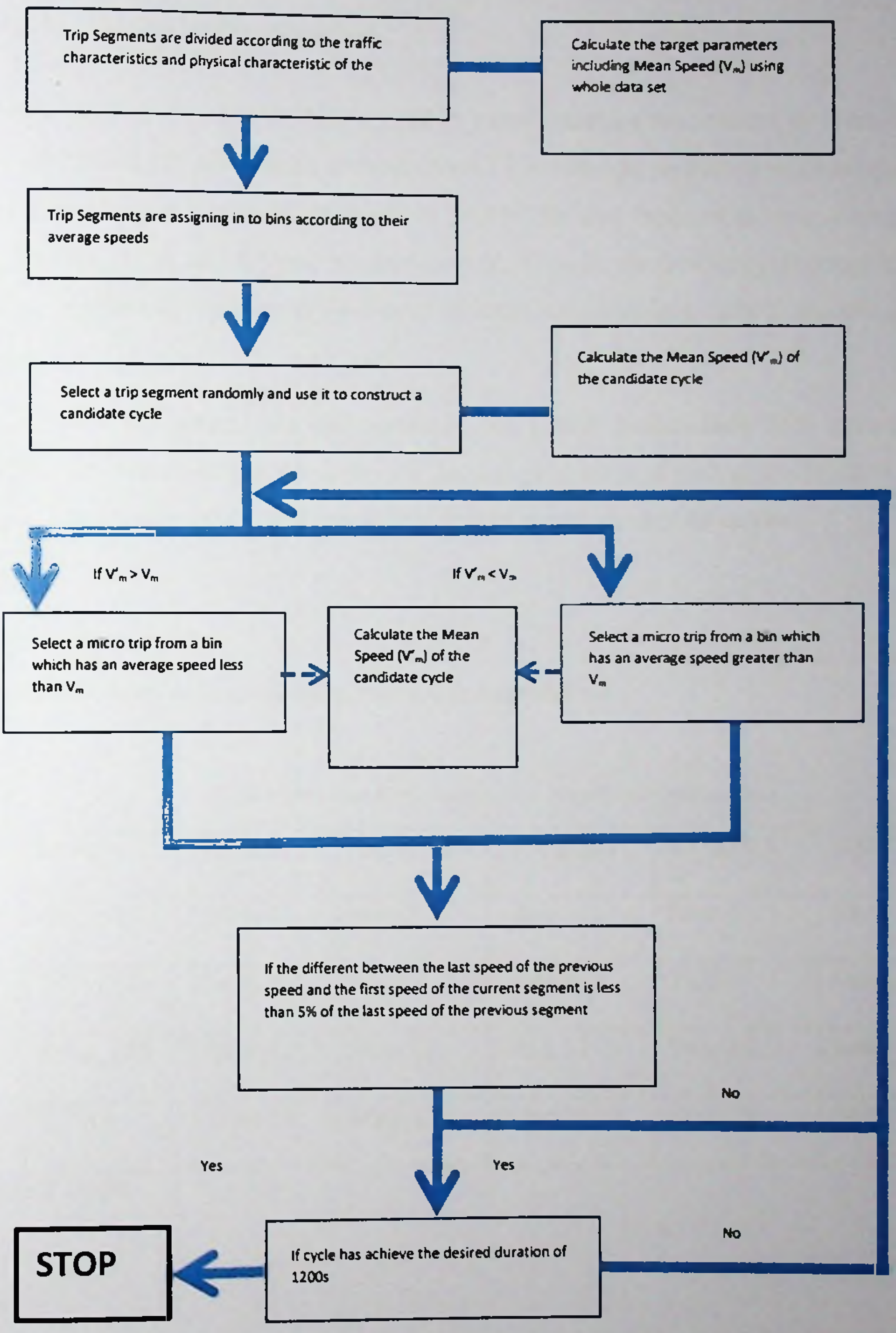


Figure 9: Methodology flow chart for construct driving cycles using segment based cycle construction

3.5.2.3. Modal cycle construction

Modal cycle construction method is used by many countries to construct their driving cycles. On road driving is captured by the sequence of acceleration, deceleration, cruising and idling and then develops a probability matrix to predict the next mode of driving. Using transition probability matrix and the time proportion of each mode, the driving cycle is constructed and then using the target parameters and the SAPD the best candidate cycle is selected as a driving cycle.

Nonetheless the method has been modified and a new method have been introduce which capture the on road driving sequence and the time proportion of each mode. Markov theory has been used for the method as did in old method of modal cycle construction.

Step 1

States have been defined using speeds and accelerations.

Table 4: Definition for the states used in transition probability matrix

km/h	$a \leq -0.8$	$-0.8 < a \leq -0.1$	$-0.1 < a \leq 0.1$	$0.1 < a \leq 0.8$	$a > 0.8$
$0 < v_m \leq 25$	State 1	State 2	State 3	State 4	State 5
$25 < v_m \leq 45$	State 6	State 7	State 8	State 9	State 10
$45 < v_m \leq 65$	State 11	State 12	State 13	State 14	State 15
$v_m > 65$	State 16	State 17	State 18	State 19	State 20

State 0 – Idle

Step 2

Then a transition probability matrix is prepared which represent the probability of mode changes from one state to another. The sample of the matrix is shown in table 5.

Table 5: Transition probability matrix for state changes

States	0	1	2	3	4	5	6	7	8	9	10	11	...	...	...	17	18	19	20
0																			
1																			
2																			
3																			
18																			
19																			
20																			

Step 3

Then calculate the time proportion of each twenty one states using population data set.

Table 6: Time proportion for each state using population data set

State	Time proportion %
0	p_0
1	p_1
2	p_2
3	p_3
4	p_4
5	p_5
17	p_{17}
18	p_{18}
19	p_{19}
20	p_{20}

Step 4

Calculate the time in each state with in the driving cycle (time allocated for each state with in 1200s duration of driving cycle)

Table 7: Time for driving cycle from each mode

State	Time for driving cycle from each mode	Probability of each state to driving cycle
0	$(1200\times p_0)-X_0$	P_0
1	$(1200\times p_1)-X_1$	P_1
2	$(1200\times p_2)-X_2$	P_2
3	$(1200\times p_3)-X_3$	P_3
4	$(1200\times p_4)-X_4$	P_4
5	$(1200\times p_5)-X_5$	P_5
6	$(1200\times p_6)-X_6$	P_6
17	$(1200\times p_{17})-X_{17}$	P_{17}
18	$(1200\times p_{18})-X_{18}$	P_{18}
19	$(1200\times p_{19})-X_{19}$	P_{19}
20	$(1200\times p_{20})-X_{20}$	P_{20}

Where X_i is the time used for diving cycle from each mode. At the beginning the X_i is equal to zero. But when the cycle is been constructed the time from each mode for the driving cycle is reduced. Then the probabilities for the driving cycle from each states are calculated as shown in the equation 4.

The probability for ith state

$$P_i = \frac{[(1200\times pi)-Xi]}{1200-\sum_{i=0}^{i=20} Xi} \quad \text{Equation 4}$$

Where Xi donates the time used from ith state to construct driving cycle. When $\sum_{i=0}^{i=20} Xi=1200$ the cycle stops.

Step 5

Calculate the new probabilities of each driving mode (table 7) and prepare a transition probability matrix for new probabilities of state changes. Example for calculating new probabilities of state changes are shown in table 8

Table 8: New transition probability matrix for state changes

State	0	1	2
0	0	$P_{0\rightarrow1} \times P_1$	$P_{0\rightarrow2} \times P_2$
1	$P_{1\rightarrow0} \times P_0$	0	$P_{1\rightarrow2} \times P_2$
2	$P_{2\rightarrow0} \times P_0$	$P_{2\rightarrow1} \times P_1$	0

Where $P_{i\rightarrow j}$ is the probability of state change from i[th] state to i[th] state

Note-

When one mode is selected, the time allocated for the respective state is reduced hence the probabilities are varies and it allow other states to increase their probabilities and then those states will have higher chance of get selected for the driving cycle.

Step 6

Initially the state 0 is selected and then form that the higher probability mode from state 0 is selected from new probability metrics. Likewise the data is selected for the driving cycle until the length of the driving cycle reach 1200s (For each selection the new probabilities are calculated and update the new transition probability matrix)

3.5.3. Cycle assessment

Many parameters have been identified for cycle assessment in the literature survey and out of those parameters 11 parameters have been identified for a cycle's assessment.

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

$$\text{Average speed} = \frac{\text{SUM of all spot speeds (including idling)}}{\textit{Number of spot speed (including idling)}}$$

2. Average running speed (vr);

$$\text{Average speed} = \frac{\text{SUM of spot speeds (excluding idling)}}{\text{Number of spot speed (excluding idling)}}$$

3. Average acceleration (a);

$$\text{Average acceleration} = \frac{\text{SUM of the acceleration}}{\text{Number of acceleration}}$$

4. Average deceleration (d)

$$\text{Average deceleration} = \frac{\text{SUM of the decceleration}}{\text{Number of decceleration}}$$

5. Time proportions of driving modes for idling (Pi)

$$P_i = \frac{\text{Time spent in driving mode of idling}}{\text{Total time}}$$

6. Time proportions of driving modes for acceleration (Pa)

$$P_a = \frac{\text{Time spent in driving mode of acceleration}}{\text{Total time}}$$

7. Time proportions of driving modes for cruising (Pc)

$$P_c = \frac{\text{Time spent in driving mode of cruising}}{\text{Total time}}$$

8. Time proportions of driving modes for deceleration (Pd)

$$P_d = \frac{\text{Time spent in driving mode of acceleration}}{\text{Total time}}$$

9. Average Micro trip duration (M)

$$M = \frac{\sum Time\ of\ micri\ trips}{Number\ of\ micri\ trips}$$

10. Root mean square acceleration (arms)

$$RMS = \sqrt[2]{\frac{1}{T}\left(\int_0^T a^2 dt\right)}$$

11. Positive kinetic energy (PKE).

$$PKE = \frac{1}{dist}\sum_{i=2}^{n}\{v_i^2 - v_{i-1}^2\ (where\ v_i > v_{i-1}) \qquad \text{Else } 0$$

After calculating the parameters for the population as well as for the candidate cycles, candidate cycle is selected as a driving cycle to represent on road traffic behaviour n selected road or region which has a lower Performance value

PV= Summation of the percentage different of the candidate cycle with the population parameters

In addition if the PV values are similar or approximately close then the SAFD is considered. And the SSD value is taken (summation of the different between SAFD of the population and candidate cycle) and the cycle which has minimum SSD value is taken as the Driving cycle for the road or that area.

CHAPTER FOUR

4. ROUTE SELECTION

4.1. Introduction

Route selection is one of the major steps in developing driving cycle because the data is collected using selected routes. If the selected routes do not represent the actual situation in Colombo area, the driving cycle will not be accurate to estimate emission inventories or fuel consumption due to inaccurate data collected using the route selected. Many methods have been identified from the literature and best methods for Sri Lanka were selected after considering the data available, traffic behaviour and availability of funds.

4.2. Route Selection to Construct a "Driving Cycle" for Traffic Engineering Purpose; Case Study: Base Line Road

Route selection is not necessary for traffic engineering driving cycles because the data is collected from the road segment where the driving cycle has to be constructed. For the case study Base Line road is taken as the route to develop a driving cycle for traffic engineering purpose.

Figure 10: Base Line Road (case study)

4.3. Route Selection for Segment Based Cycle Construction; Case Study: Southern Highway.

Representative Data Set

It is well known fact that travel behaviour is varied due to several reasons such as nature of driver, trip purpose and origin destination. For this study the trip purpose and the origin destination is taken in to account when selecting the samples. When selecting the trips for track the speed time variation in the road links overall enter exit data were taken in to account and trips were selected proportionate to the average trip pattern. Table 9 shows the actual number of trips for average day.

Table 9: Number of trips made in average day

	KOT	KT	GG	DG	WP	KGH	BG	PD
KOT	0	150	1002	465	246	376	121	1248
KT	147	0	99	65	27	43	11	104
GG	1073	91	0	144	61	76	20	201
DG	481	53	129	0	37	44	9	86
WP	197	19	50	43	0	39	9	49
KGH	364	35	63	39	42	0	44	183
BG	112	10	27	6	12	38	0	45
PD	1907	94	172	95	51	191	67	0

KOT- Kottawa, KT- Kahathuduwa, GG- Galganigama, DG- Dodangoda, WP- Walipanna, KGH- Kurudugahahathakma, BG- Baddegama, PD- Pinnaduwa

Table 10: Number of trips for data collection

	KOT	KT	GG	DG	WP	KGH	BG	PD
KOT	0	2	10	5	2	4	1	12
KT	1	0	1	1	0	0	0	1
GG	10	1	0	1	1	1	0	2
DG	5	1	1	0	0	0	0	1
WP	2	0	0	0	0	0	0	0
KGH	4	0	1	0	0	0	0	2
BG	1	0	0	0	0	0	0	1
PD	19	1	2	1	1	2	1	0

4.4. Route Selection for Construct a "Driving Cycle" for Fuel Economy and Emission Purpose

4.4.1. Research Gap

Many countries have been selected routes using basic methods such as selecting routes by researchers' knowledge regarding the traffic behaviour of the region or the area. Furthermore some countries used advance methods where lot of traffic data is required. Therefor it is necessary to find a proper method for route selection which will not underestimate nor overestimate the fuel consumption and emission in Colombo region with the available data.

Routes were selected for the intercity trips using available OD data of main corridor where the vehicles enter to Colombo city.

4.4.2. Route Selection Methodology for intercity trips

Step 1: Select OD locations for Colombo

Identify the main corridors where the vehicles enter to Colombo and then select point which could capture the majority of the vehicles arrived. In past such routes have been identified and those locations are mentioned below.

1. Gamsabha Junction(Aththidiya road)
2. Piliyandala
3. Mattakkuliya (Canal Road)
4. Grandpass (Negambo Road)
5. Rajagiriya (Sri Jayawardanapura Mawatha)
6. Kohuwela (Horana Road)
7. High Level
8. Dehiwala (Galle Road)
9. Kelanithissa(Kandy road)
10. Orugodawatta (Awissawella Road)

Figure 11: OD locations for Colombo

Step 2

Conduct an OD survey for those selected locations. Since OD data is available for those locations Step 1 and Step 2 can be skipped. And the selected location have been showed in figure11.

Step 3

Analyse the OD matrixes and superposition those matrixes in to one matrix. Then the routes which has higher traffic flows can be identified. After superimposed the routes the routes which are occupied more than 70% of the total vehicle fleet across the OD location were selected as the representative routes and others were avoided. 57 routes were identified initially using OD matrix and it is shown in Appendix 1

Step 4

Select the roads which have higher frequencies across the OD locations were further narrowed down considering daily traffic on selected roads. Road which have lesser daily traffic were avoided because the impact of those road to the representativeness will be lesser compared to the selected roads. Thirty three routes were selected and are included in Appendix 2.

4.4.3. Route selection for intra city trips

Since OD data of the intra city trips were not available alternative method has been adopted. To capture the driving pattern and select representative routes model was developed using GIS. There the Land use pattern and population density was considered. Then the trip generators and trip attractors were identified. Using road network in Colombo city main arterial and collector roads were identified between trip generates and attractors.

Daily Traffic data (DT)

Daily traffic (MCC) data are available for many routes in Colombo. But in some places there is lack of available information. Using Expert judgment and knowledge of the researchers the DT data were interpolated for such places using the data available nearby routes.

Number of trips from each route were selected proportionate to the Daily Traffic (MCC)

Step 1: Identify the Trip Generators and trip Attractors by GN division

Population data and land use data is taken to identify the trip generators and trip attractors.

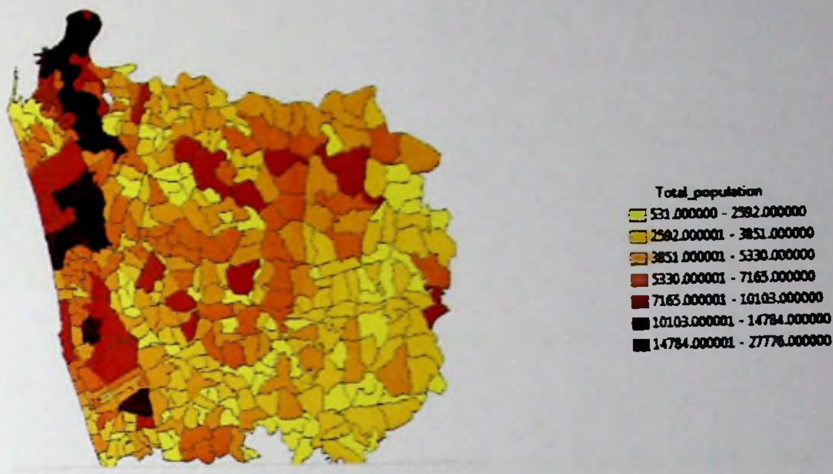


Figure 12: Total population in GN divisions

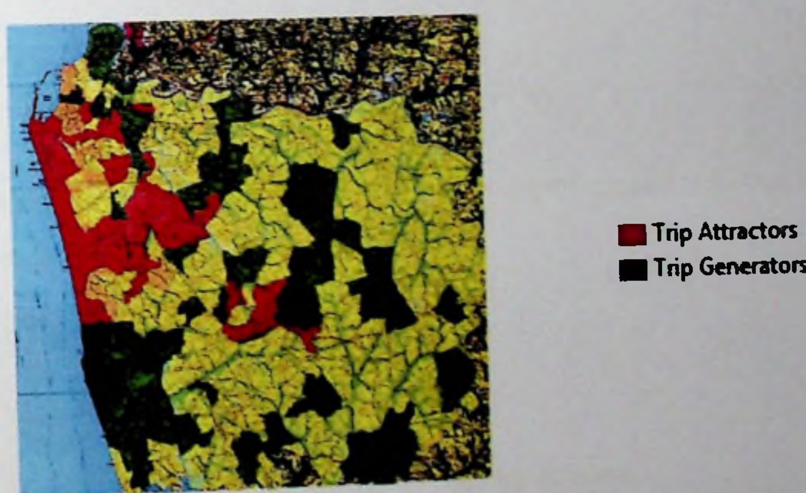


Figure 13: Trip generators and trip attractors

Step 2: Select the routes which connect trip generators and trip attractors

Route network is extracted using JOSM and the shape file to use in ArcGIS was prepared using QGIS. After extracting the road layer it was overlay on the map which contain the trip generators and trip attractors.

Figure 14: Routes connecting trip generators and trip attractors

Seventy two routes were identified which contains major and minor roads which could represent the actual intra city driving in Colombo region and shown in Appendix 3

4.4.4. Representative Routes for Intercity and Intra city Trips

To collect data selected routes for intercity and intra city were superimposed in to one layer and then the route map is taken.

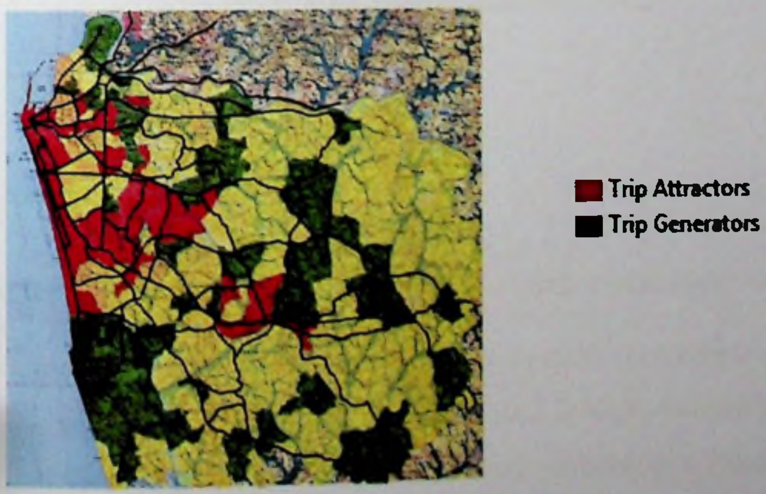


Figure 15: Superimposed road layer for intercity and intra city

Then the routes were divided into links using physical junctions. Links were divided such that which could be used to construct any route using few links (as given in methodology).

Figure 16 shows the links for the selected road network and for the convenience of further analysis node numbers were assigned to physical junctions and numbers were assign to road links. Selected road links for data collection are given in Appendix 4

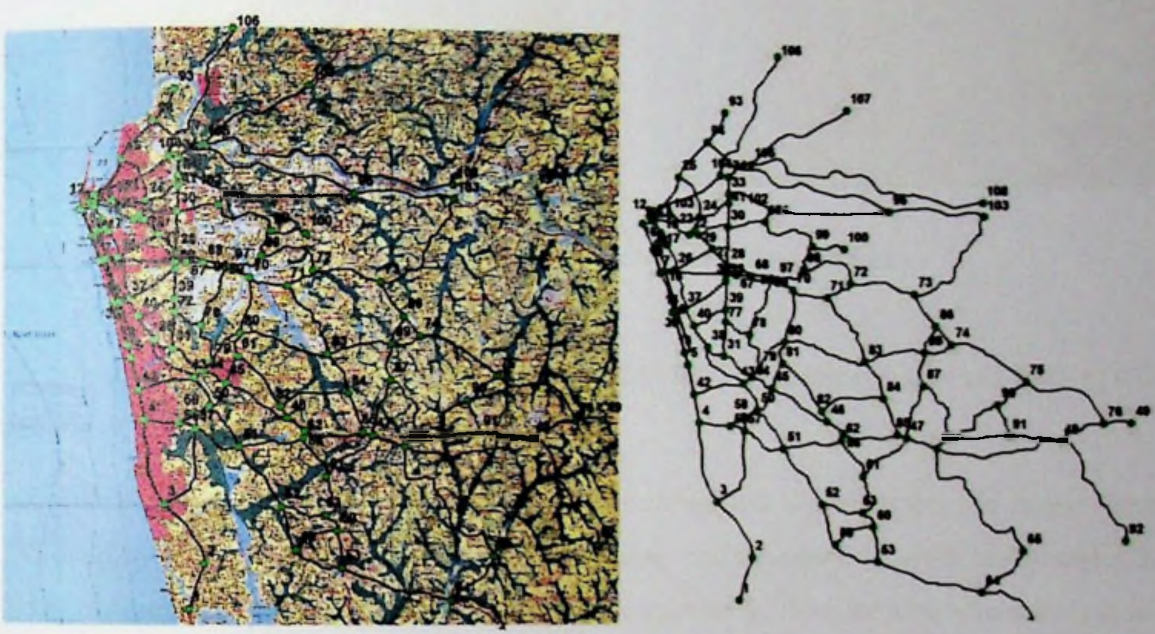


Figure 16: Route links for selected road network

4.4.4.1. Selection of Road Links

Step 1: Identify the traffic behaviour in the road/road link with in the time periods of the day

In selected routes the traffic behaviour vary according to the time period of the day unless the route is in the trip attractor. Normally the traffic flow is high towards the Attractor, but the problem is that the trip generators and attractors shifts with the time (Time period of the day). In the morning the trip attractors are mainly the commercial areas of Colombo and in the evening the trip generators (Home and Garden areas) will be the attractors and then the traffic flow is high towards that direction as shown in figure 17.

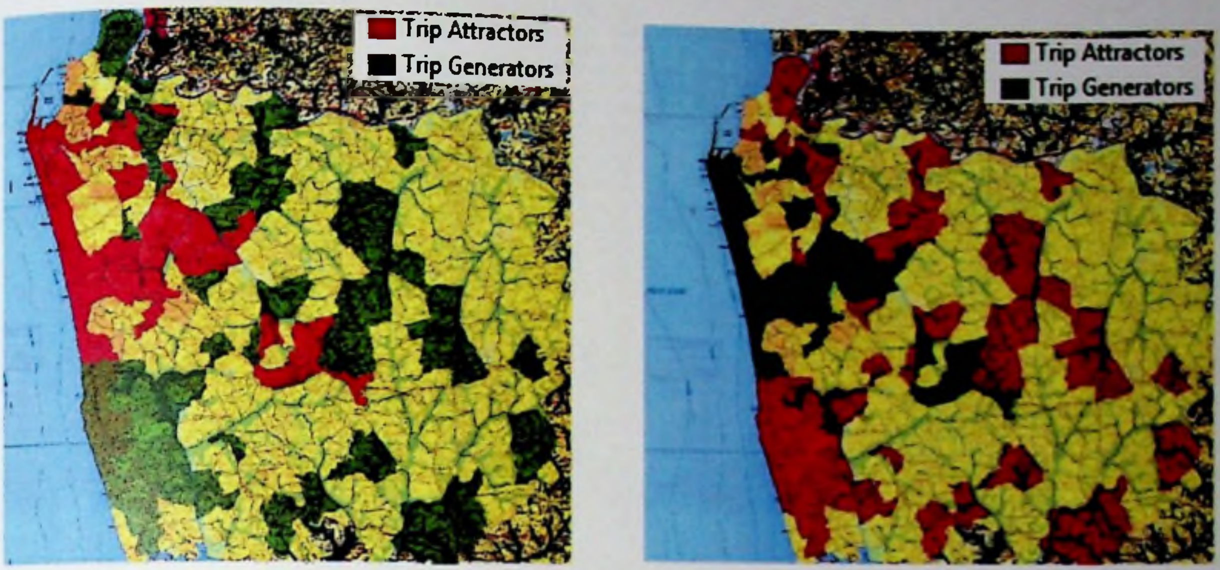


Figure 17: Trip generators and attractors in the morning and evening

Step 2: Assign the traffic volumes for respective road link and categories the road links in to groups

After selecting the routes which connect trip generators and trip attractors the routes were assigned in to five road groups according to the daily traffic volumes shown in Appendix 5. Some assumptions have been made using expertise knowledge from the area where there is no available data.

Table 11: Criteria for dividing road groups

Group Number	Total Traffic Volume (No of Vehicles)
1	Up to 15 000
2	15001 to 25000
3	25001 to 35000
4	35001 to 50000
5	Above 50000

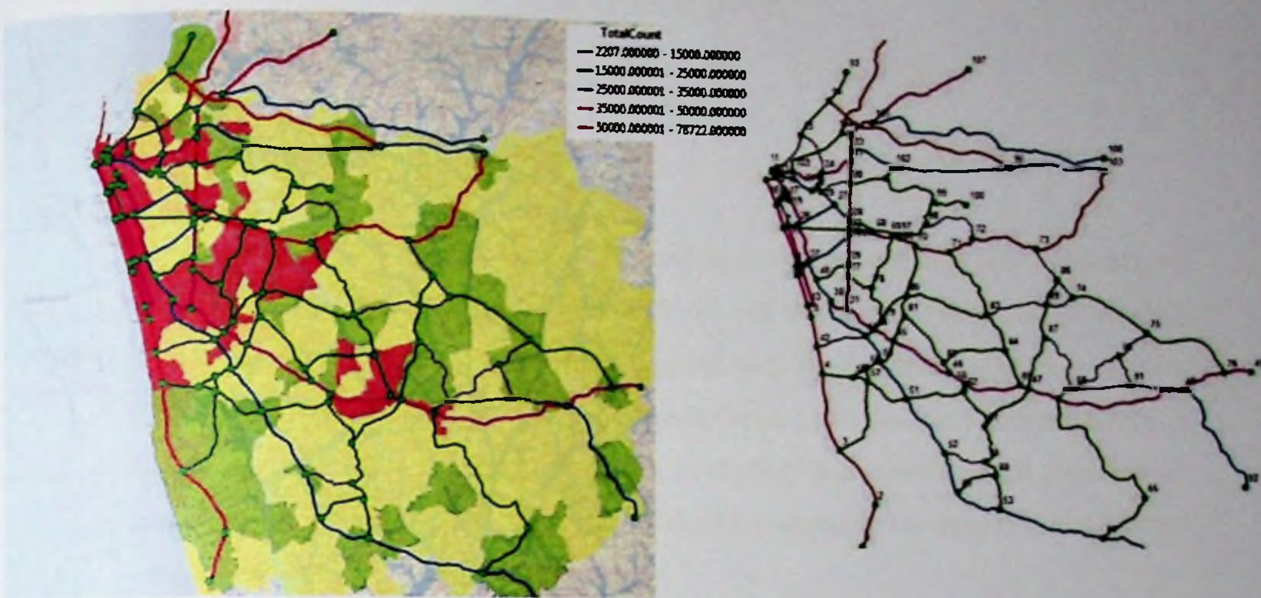


Figure 18: Road groups

Step 3: Data is collected using selected route links and then according to the road group data sample is prepared proportionate to the daily traffic and the hourly volume on roads

CHAPTER FIVE

5. DATA COLLECTION

5.1. Introduction

Data collection is one of the major steps in developing driving cycles. The accuracy of the data will have a huge impact of the accuracy and representativeness of the driving cycle. Therefore it is necessary to select a better method of collecting data which will grasp the traffic pattern in the considered road or area. Also the cost for implementing the method is another important parameter. In driving cycle development process the major cost component is data collection. Therefore whatever the method used has to be economical due to limitation of funds.

5.2. Data collection for traffic engineering purpose

Driving cycle for traffic engineering purpose is to make traffic engineering decisions. Therefore the developed model should represent the actual traffic behaviour in specific time period not the average model as in fuel consumption and emission purpose. For the case study Baseline Road was used. Thirteen trips were collected using on-board measurement method. The driving cycle is developed using morning peak traffic flow from Orugodawatta temple to High-level road (From Colombo) to represent the traffic behaviour at the morning peak. Same as this it is possible to develop the driving cycles for hourly basis of for major peaks, inter peaks and off peaks.

5.3. Data collection for emission purpose

To estimate emission inventories and setting up emission standard data is collected using highly congested roads. To measure the deviation of peak driving cycle from average traffic behaviour data is collected proportionate to the daily traffic and the traffic variation of the road itself. Since the roads are divided in to five groups (table 11) it is possible to identify the routes to collect data for peak driving cycle.

From each group the data was collected and the collected number of data are shown in table 12. Total hours of data collected in peaks, inter peaks and off peaks are is around 105 hr.

Table 12: Number of data links collected for each road group

	Morning Off-peak	Morning Peak	Inter Peak1	School Peak	Inter Peak2	Evening Peak	Night Off-peak	Total
Road Group 1	1	3	14	3	7	10	2	40
Road Group 2	13	10	36	20	22	52	9	162
Road Group 3	9	17	30	25	18	28	13	140
Road Group 4	8	27	49	36	33	40	16	209
Road Group 5	9	23	20	17	21	25	7	122

5.4. Segment-based cycle construction

Segment based cycle construction method is used to construct a driving cycle where there is less variation in speed and less stops. Ex- Expressways. Since there are less stops (in express ways there are no stops), micro trip method cannot be adopted. Also if there is less speed variation it is difficult to use model cycle construction method. Therefore segment based cycle construction method is used to construct driving cycles in Expressways and Southern Highway is taken as a case study.

It is necessary to select those trips proportionate to the actual number of trip in an average day but within one day it is difficult to collect as estimated because of the constrains in time and resources. Table 13 shows the number of trips between road links in average week day and table 14 shows the actual trips made for each enter and exit categories. When selecting the vehicles for data collection the effort has been given to select the trips as estimated as much as possible

Table 13: Number of trips made in average day

	KOT	KT	GG	DG	WP	KGH	BG	PD
KOT	0	150	1002	465	246	376	121	1248
KT	147	0	99	65	27	43	11	104
GG	1073	91	0	144	61	76	20	201
DG	481	53	129	0	37	44	9	86
WP	197	19	50	43	0	39	9	49
KGH	364	35	63	39	42	0	44	183
BG	112	10	27	6	12	38	0	45
PD	1907	94	172	95	51	191	67	0

Table 14: Number of trips for the data collection

	KOT	KT	GG	DG	WP	KGH	BG	PD
KOT	0	1	6	6	1	3	0	6
KT	1	0	0	0	1	0	0	0
GG	3	0	0	1	0	1	1	1
DG	4	0	0	0	1	1	0	3
WP	1	0	0	1	0	0	0	1
KGH	2	0	0	0	1	0	0	1
BG	0	1	0	0	1	0	0	0
PD	2	0	2	1	1	1	2	0

Data collection is done from 5 am to 7pm to capture the travel behaviour in peaks and off peaks with in the day. Data was collected using five GPS Sports Recorder (BT-Q1300ST) which have accuracy of one meter. Data was collected using light vehicles (cars and vans) since the research was restricted to measure the performance of the light vehicles.

Data collection is done using on board measurement method and to eliminate the drawbacks (In this method the major drawback is that the driver knows that he is been monitoring throughout the driving, hence the driving behaviour can be varies from actual driving behaviour) of the method the GPS instruments were given to the drivers who uses the road at the entrances and collected at the exits.

5.4.1. Data Analysis

Data was analysed and identified the point where the data set is to be segmented. Two criteria have been introduced. To select a points either criteria should be satisfied.

- There should be three or more links between adjacent exit and entry point
  - It is to make sure the segment in not too large. (The accuracy of the cycle depend on the relative length of the segment to a whole trip.
- Should isolate horizontal curvatures
  - To make sure the speed variation due to horizontal curvature will not affect to the straight segments. Hence it will not average the effect of curvature with other segments.

Then the segments were divided and the median speed of those segments have been identified. The results are presented in figure 19 and the points coordinates are shown in table 15.

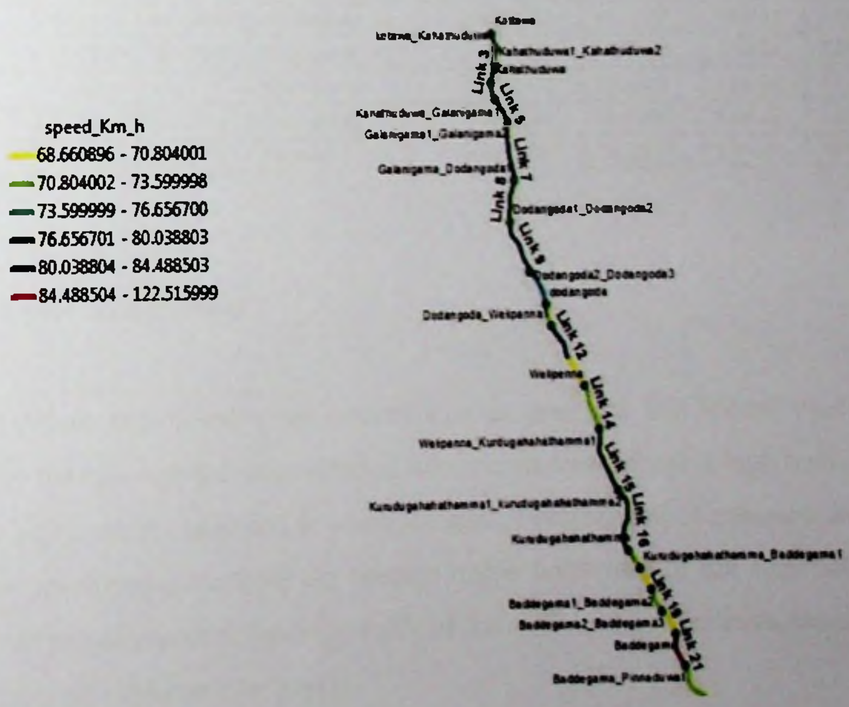


Figure 19: Road segments for driving cycle construction

Table 15: Coordinate of the selected points for segmentation

	From	Latitude	Longitude	To	Latitude	Longitude	Link No	distance (km)
1	Kottawa	6.837795	79.98156	Kahathuduwa1	6.822125	79.98559	Link 1	1.8
2	Kahathuduwa1	6.822125	79.98559	Kahathuduwa2	6.804228	79.98508	Link 2	2
3	Kahathuduwa2	6.804228	79.98508	Kahathuduwa	6.783859	79.98029	Link 3	2.29
4	Kahathuduwa	6.783859	79.98029	Galanigama1	6.765193	79.98525	Link 4	2.14
5	Galanigama1	6.765193	79.98525	Galanigama2	6.741327	79.99881	Link 5	3.06
6	Galanigama2	6.741327	79.99881	Galanigama	6.716863	80.00013	Link 6	2.7
7	Galanigama	6.716863	80.00013	Dodangoda1	6.677565	80.00719	Link 7	4.45
8	Dodangoda1	6.677565	80.00719	Dodangoda2	6.63187	80.00033	Link 8	5.15
9	Dodangoda2	6.63187	80.00033	Dodangoda3	6.577985	80.02436	Link 9	6.63
10	Dodangoda3	6.577985	80.02436	Dodangoda	6.541703	80.04342	Link 10	4.62
11	Dodangoda	6.541703	80.04342	Welipanna1	6.518509	80.05003	Link 11	2.68
12	Welipanna1	6.518509	80.05003	Welipanna2	6.482617	80.07015	Link 12	4.63
13	Welipanna2	6.482617	80.07015	Welipenna	6.452672	80.08913	Link 13	3.93
14	Welipenna	6.452672	80.08913	Kurdugahahathamma1	6.405463	80.10527	Link 14	5.55
15	Kurdugahahathamma1	6.405463	80.10527	Kurudugahahathamma2	6.338609	80.1276	Link 15	8.02
16	Kurudugahahathamma2	6.338609	80.1276	Kurudugahahathamma	6.272791	80.1382	Link 16	8
17	Kurudugahahathamma	6.272791	80.1382	Baddegama1	6.25208	80.15208	Link 17	2.76
18	Baddegama1	6.25208	80.15208	Baddegama2	6.228958	80.16496	Link 18	2.96
19	Baddegama2	6.228958	80.16496	Baddegama3	6.205237	80.17822	Link 19	3.02
20	Baddegama3	6.205237	80.17822	Baddegama	6.180694	80.19413	Link 20	3.29
21	Baddegama	6.180694	80.19413	Pinnaduwa1	6.145675	80.20461	Link 21	4.22
22	Pinnaduwa1	6.145675	80.20461	Pinnaduwa2	6.102066	80.23452	Link 22	6.23
23	Pinnaduwa2	6.102066	80.23452	Pinnaduwa	6.073219	80.26255	Link 23	4.49

5.5. Model Cycle construction

The data used Micro trip based cycle construction is used for the Model cycle construction. For the emission the data collected from routes where there is high traffic flow is used to represent the emission at worst scenario. Furthermore to measure the variation of the developed cycle from the average traffic behaviour of the area data sets were selected proportionate to the daily traffic of the roads and the traffic variation of the road (peaks, off peaks or inter peaks)

Same as for the fuel economy purpose the data is collected proportionate to the daily traffic and the traffic variation of the road to represent the average traffic behaviour of the Colombo city. Number of collected trip links are shown in table 12.

CHAPTER SIX

6. CYCLE CONSTRUCTION

6.1. Introduction

Cycle construction is one of the major steps of developing driving cycles. A proper route selection method gives representative routes, proper data collection gives accurate data set which represents the actual behaviour of the traffic flow and the driver. After collecting accurate data which gives the actual traffic pattern in the area of concern and actual behaviour of the driver it is necessary to develop a model which is closely match to the collected data sample (which is considered as population) parameters. The cycle construction method act an important role in developing the model using population data.

According to the traffic behaviour and the purpose of the driving cycle the method of construction is varies. It is very important to identify the proper method for specific purpose. Study has done to identify the major methods of cycle construction, advantages, disadvantages and limitations.

6.2. Software Developed for Cycle Construction

Form the data population data is assigned in to segments by considering many parameters according to the purpose of the cycle. It is difficult to work with such a large dataset manually and calculate each and every parameter one by one for each and every time when the segment is selected. Therefore two software were developed for the purpose.

- DC2013
- DCC2014

6.2.1. DC2013 (Micro Trip Based and Segment Based Driving Cycle Construction)

DC2013 was developed in 2013 by Galgamuwa, researcher at transportation engineering division, university of Moratuwa for developing driving cycle for traffic engineering purpose, emission and fuel economy purpose. Still it is the only software available in Sri Lanka to develop traffic related driving cycles. The software can construct traffic related driving cycle using segment based cycle construction and it can develop driving cycles for emission purpose and fuel economy purpose by using Micro trip based cycle construction method and segment based cycle construction method.

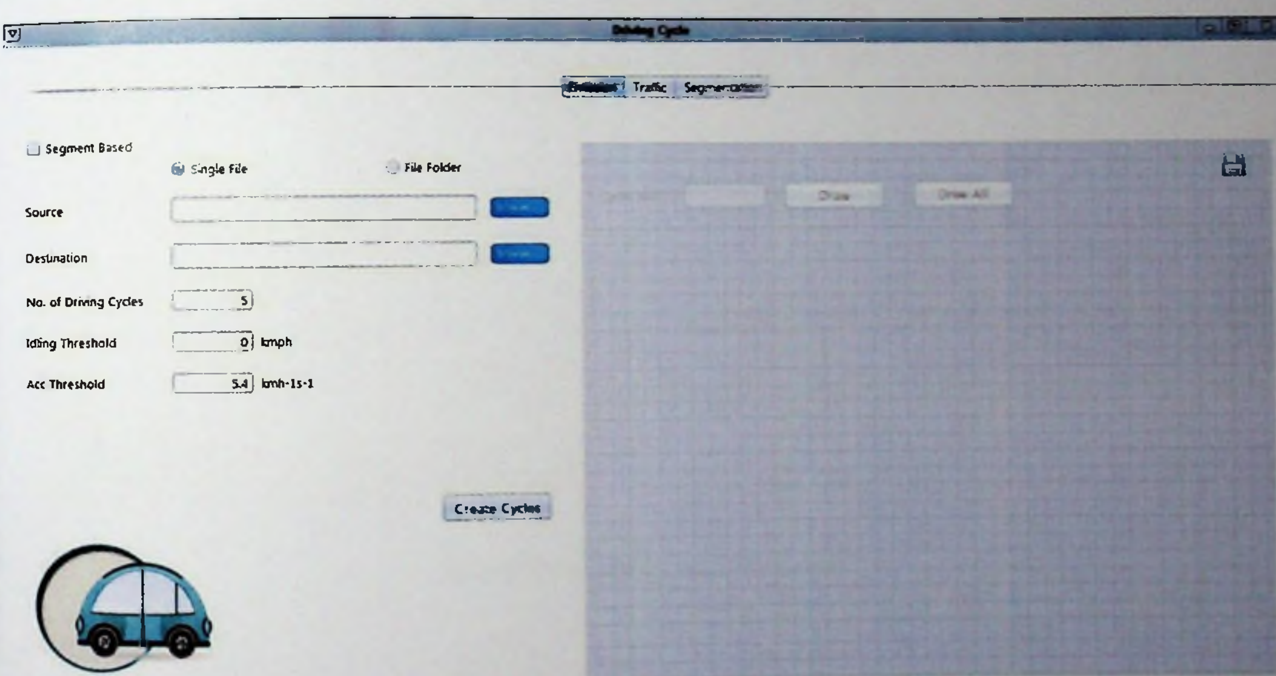


Figure 20: Interphase of DC2013 software

6.2.2. DCC2014 (Modal-based Driving Cycle Construction)

DCC2014 is the latest software developed to construct driving cycles for emission and fuel economy purpose. The software uses Modal cycle construction method. But there are some limitation of the software such as it cannot use to develop driving cycles for traffic engineering purpose, the memory requirement(RAM) is higher than DC2013 and time spend to produce a driving cycle is more than DC2013. If the dataset is too large and the memory capacity is less the output will not be produced.

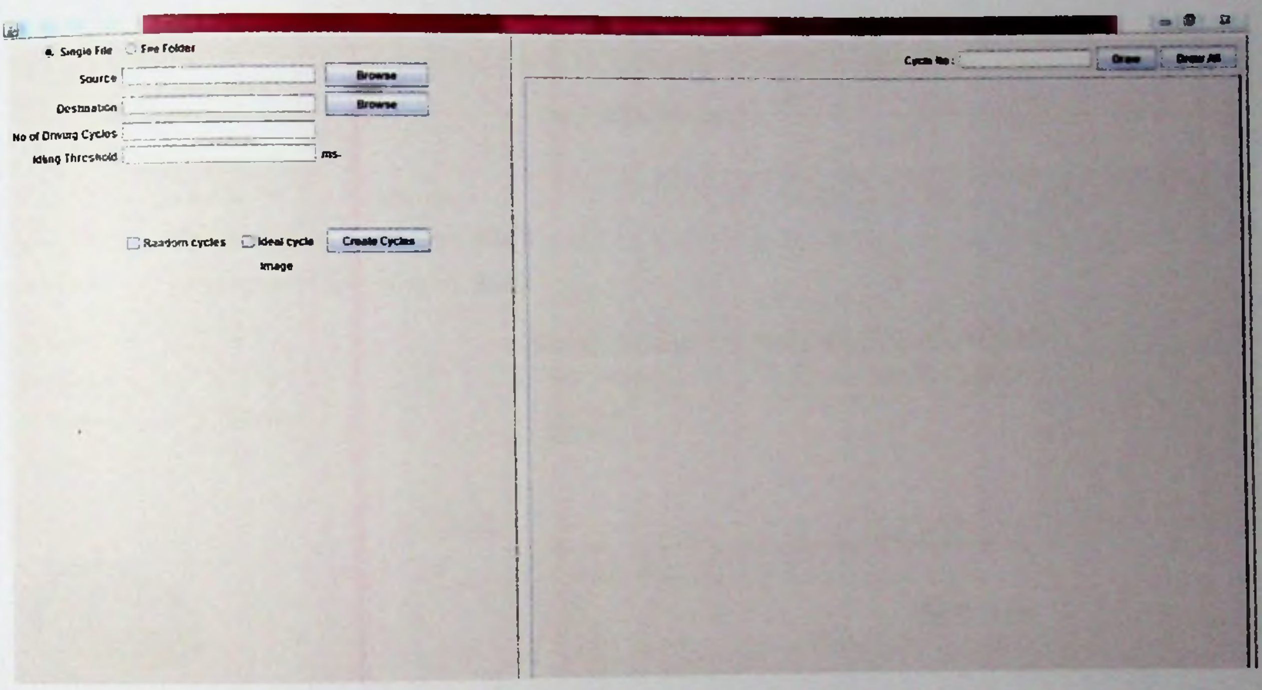


Figure 21: Interphase of DCC2014 software

6.3. Cycle Construction for Emission Purpose

6.3.1. Introduction

Driving cycle for emission purpose should capture the actual driving pattern with mode changes in considered area. The parameters have carefully selected and two software were constructed (DC2013 and DCC2014). There are unique applications, advantages and limitation for the constructing methods.

6.3.2. Micro Trip based cycle construction (DC2013)

Software was developed to perform the cycle construction as described in methodology in section 3.5.2.1. The collected data (In Colombo region) was fed in to software. And the candidate cycles were developed for approximately 1200s time period.

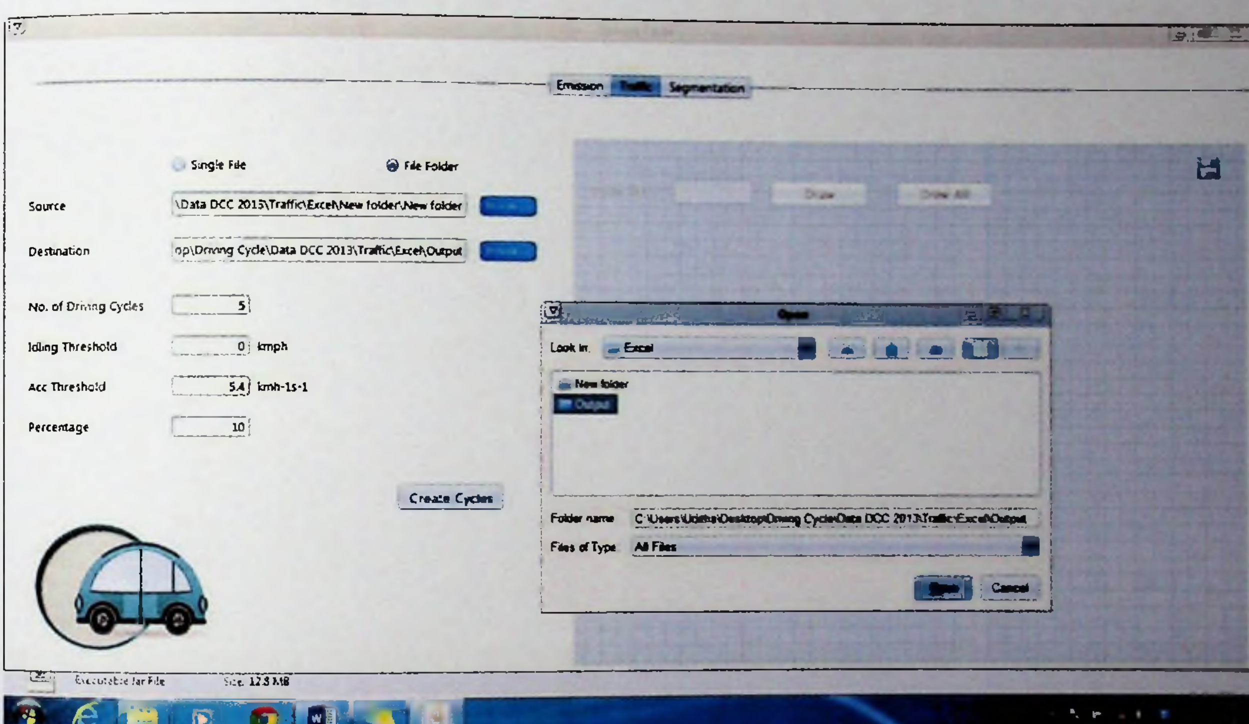


Figure 22: Interphase of DC2013 (Micro trip based cycle construction)

Three output were given by the software

1. Constructed candidate cycles with analysis

Candidate cycles were constructed according to the given methodology in chapter three. Ten number of driving cycles were constructed and among them the candidate cycle which has the lower deviation with the population is selected as driving cycle. To evaluate the driving cycle eleven parameters were used as given in methodology and the PV value was used to select the cycle with lower deviation. Analysis of driving cycle is given in Appendix 6 (a) and (b).

2. Segmented bins and average speed bins

Segmented micro trips according to average speeds were generated and it is given as an output file in Excel format. Ten segments were generated for the analysis and the format is given in figure 23.

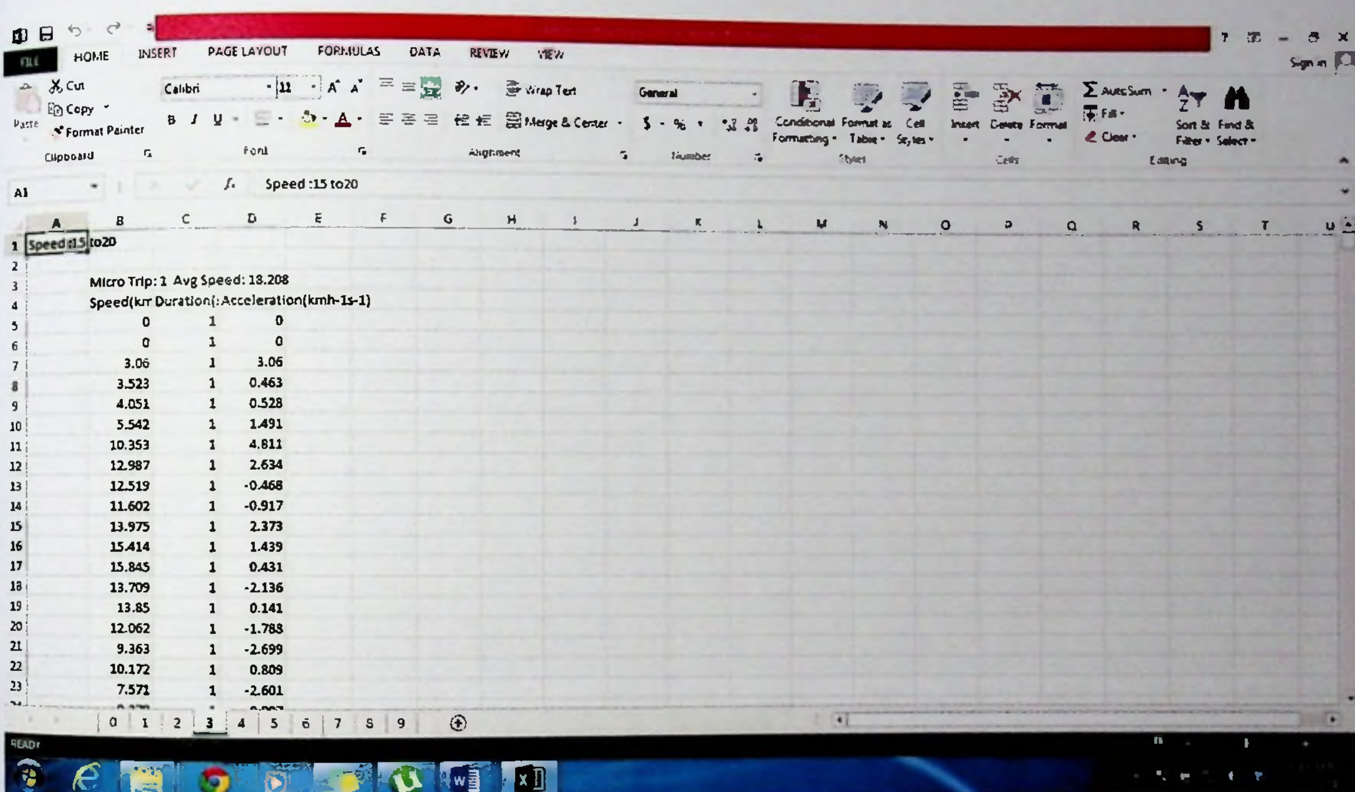


Figure 23: Segmented bins according to average speed

3. Graphs of constructed candidate cycles with cycle parameters

The third output given from the software is graphs constructed for each candidate speed lists (time vs speed). Sample is shown in figure 24

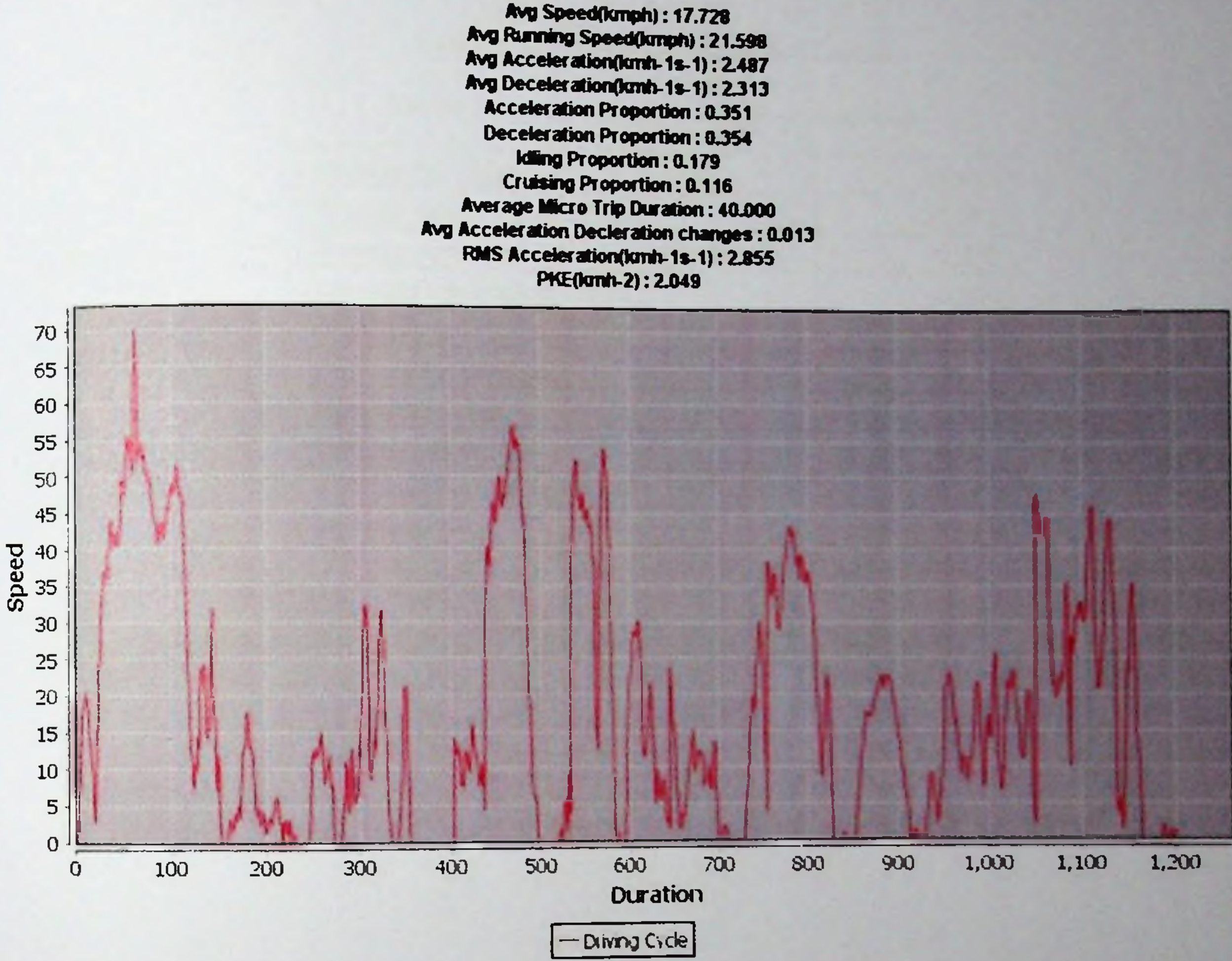


Figure 24: Graphical representation of a candidate cycle

6.3.2.1. Evaluating the Candidate cycles to select a representative Driving cycle

100 driving cycles were constructed and ten candidate cycles were selected using parameters of each candidate cycle for further analysis. The analysis of selected driving cycles are given in appendix 6 (a) and (b). Performance Value is taken to

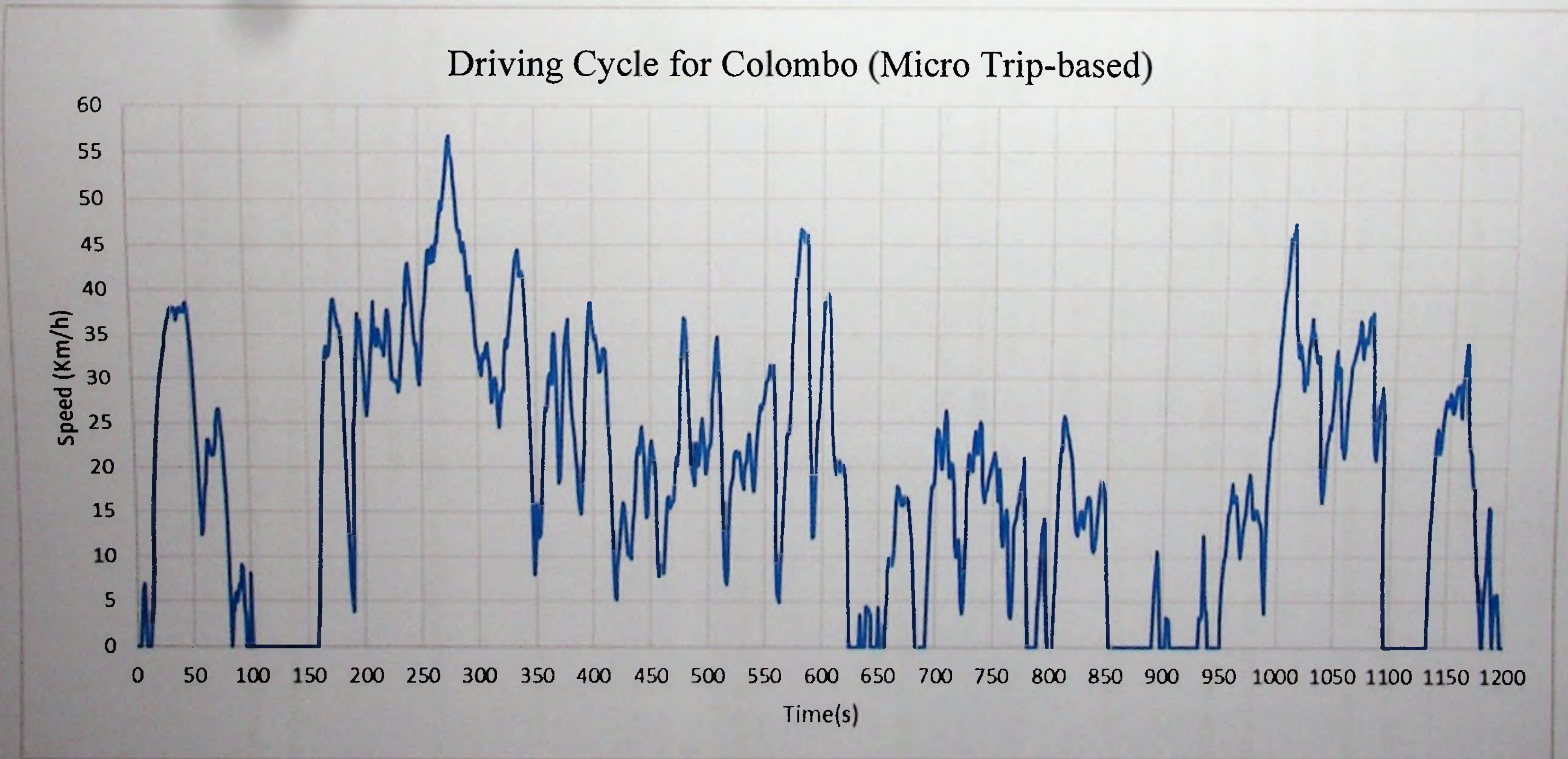
evaluate the candidate cycle. Cycle 1 and cycle 10 has PV value of 0.608 and 0.739. Since the PV values are approximately equal SSD was considered. Cycle 1 has SSD of 0.014 and cycle 10 has 0.026. Therefore the cycle 1 was selected as representative cycle for Colombo.

Driving Cycle for Colombo, Sri Lanka

Table 16: Parameters of selected candidate cycle of Colombo

Average Speed (km/h)	18.883
Average Running Speed (km/h)	23.703
Average Acceleration (kmh-1s-1)	0.222
Average Deceleration (kmh-1s-1)	0.196
Acceleration Proportion	0.382
Deceleration Proportion	0.316
Idling Proportion	0.203
Cruising Proportion	0.099
RMS Acceleration(kmh-1s-1)	0.011
PKE(kmh-2)	1.916

Graphical representation of selected cycle is given in figure 25.



Driving Cycle for Colombo (Micro Trip-based)
Speed (Km/h)
0
5
10
15
20
25
30
35
40
45
50
55
60
Time(s)
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 1050 1100 1150 1200

6.3.3. Segment based cycle construction (DC2013).

In DC2013 the option is given to develop driving cycles using segment based cycle construction method. Previously the points for the segmentation were identified and using those points, KML file was produced using ArcGIS.

Points were exported in to KML file and fed to the software. And then segmented the data files according to given points. Then those segmented data files are used to develop a segment based emission driving cycle.

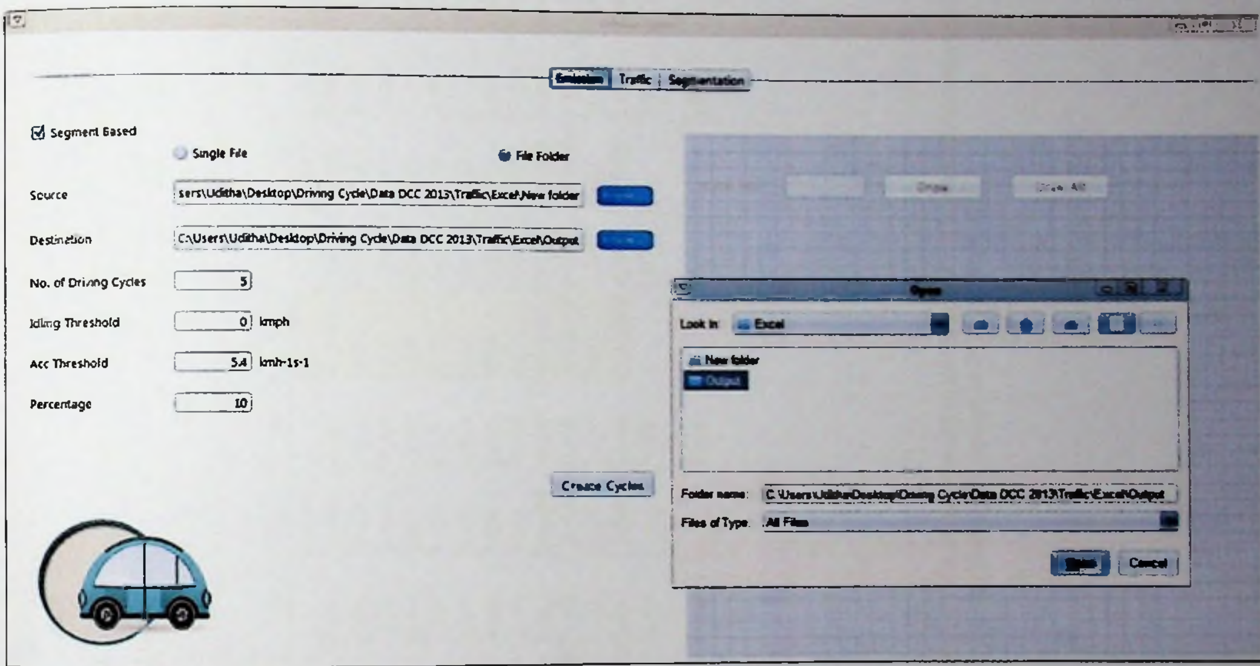


Figure 26: Interphase of DC2013 (Segment based cycle construction)

Using software according to the given methodology three types of outputs were taken as in the micro trip based cycle construction.

1. Constructed candidate cycles with analysis
   As in micro trip based cycle construction candidate speed lists and analysis of the candidate cycles with population parameters are generated in excel format and the sample is shown in figure 27.

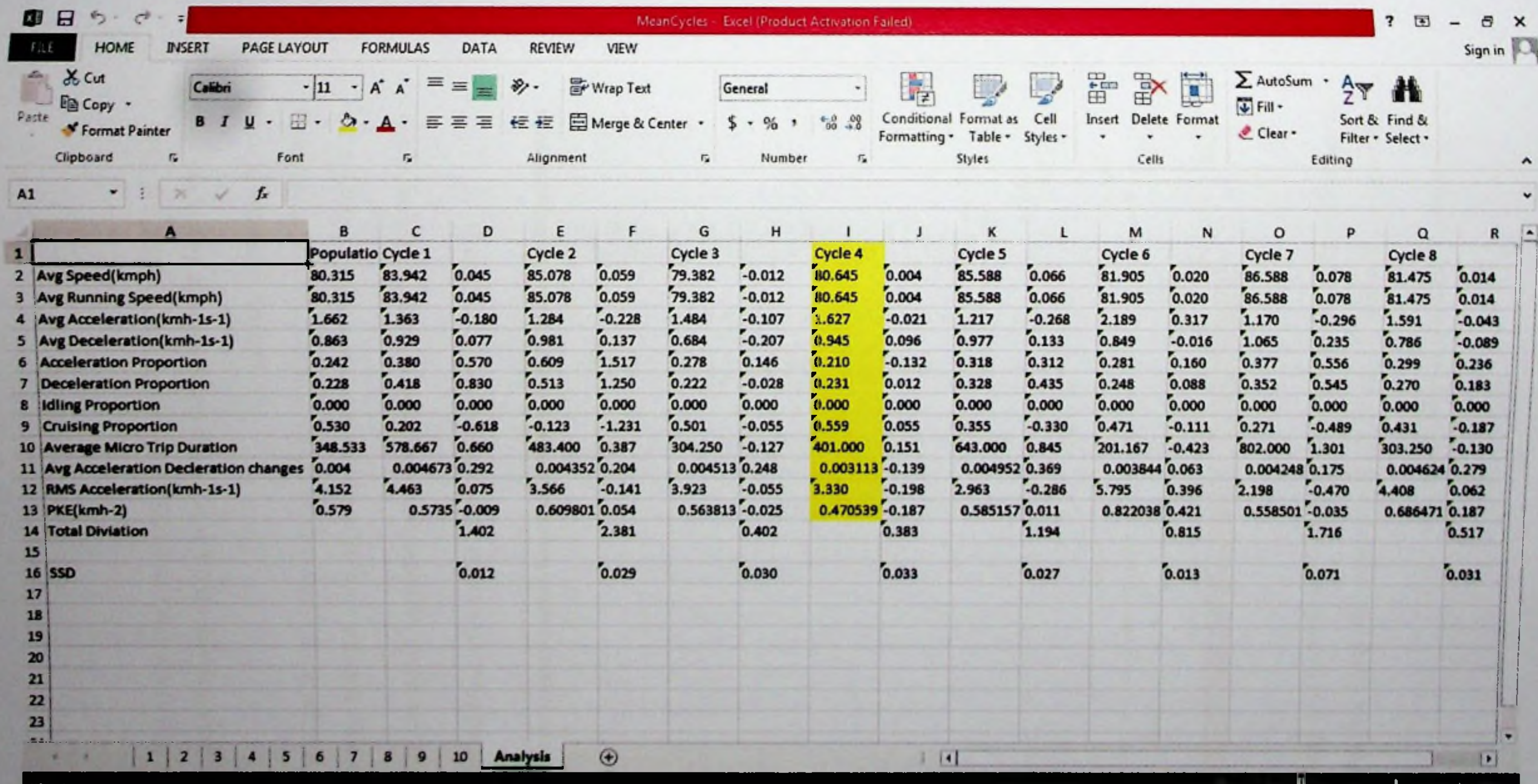
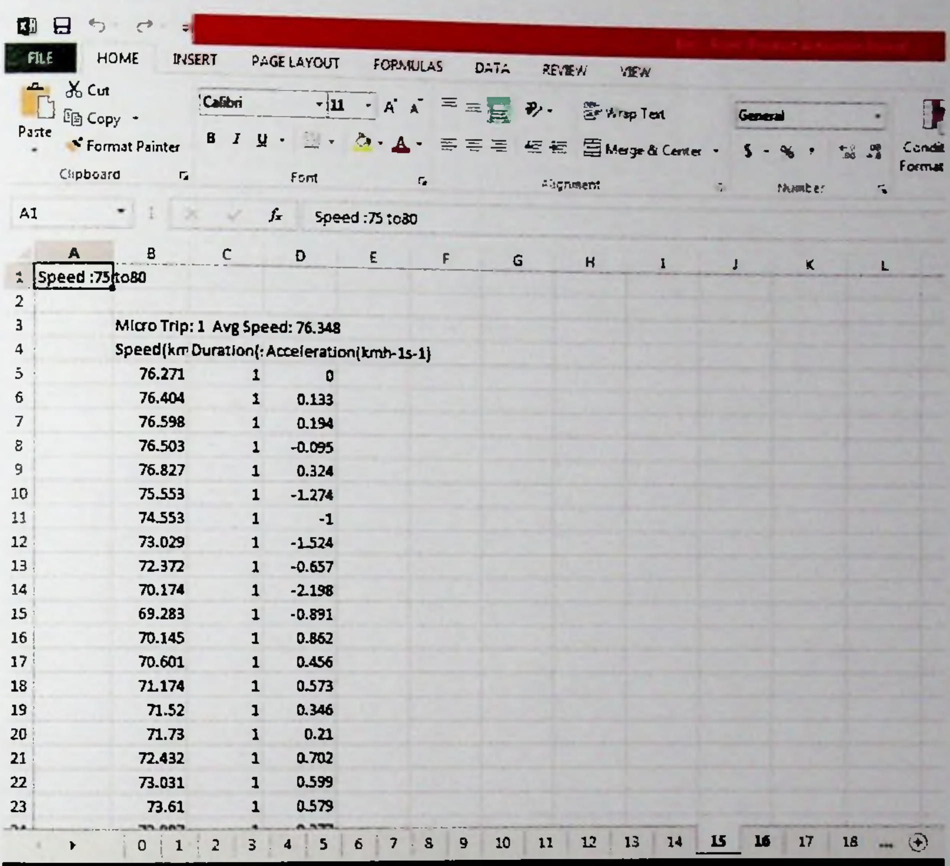


Figure 27: Candidate cycle speed lists with analysis

2. Segmented bins and average speed bins

Segments are assigned in to average speed classes and those average speed bins with speed segments are given in a excel format as a output and it is shown in figure 28



	A	B	C	D
1	Speed :75 to80			
2				
3		Micro Trip: 1 Avg Speed: 76.348		
4		Speed(km Duration(: Acceleration(kmh-1s-1)		
5		76.271	1	0
6		76.404	1	0.133
7		76.598	1	0.194
8		76.503	1	-0.095
9		76.827	1	0.324
10		75.553	1	-1.274
11		74.553	1	-1
12		73.029	1	-1.524
13		72.372	1	-0.657
14		70.174	1	-2.198
15		69.283	1	-0.891
16		70.145	1	0.862
17		70.601	1	0.456
18		71.174	1	0.573
19		71.52	1	0.346
20		71.73	1	0.21
21		72.432	1	0.702
22		73.031	1	0.599
23		73.61	1	0.579

Figure 28: Average speed bins for segment based cycle construction

3. Graphs of constructed candidate cycles with cycle parameters

Finally the graphical representation of those candidate cycles are given in JPG format.

100 candidate cycles were constructed and 10 were selected after evaluating the PV (Performance Value). The analysis and parameters for the candidate driving cycles are given in appendix 7(a) and 7(b).

After evaluating the parameters cycle 3 and 4 were selected were the PV values are 0.521 and 0.765. After considering the SSD cycle 3 was selected as a driving cycle for emission purpose in southern expressway and the speed list of the graphical representation of selected candidate cycle is shown in figure 29.

Table 17: Analysis of selected cycle with population parameters

	Population	Cycle 3	
Average Speed(km/h)	80.315	79.382	0.0110
Average Running Speed(km/h)	80.315	79.382	0.0110
Average Acceleration(m/s2)	0.112	0.115	0.0132
Average Deceleration(m/s2)	0.055	0.042	0.0893
Acceleration Proportion	0.242	0.278	0.0591
Deceleration Proportion	0.228	0.222	0.0117
Idling Proportion	0	0	0
Cruising Proportion	0.53	0.501	0.2358
RMS Acceleration(m/s2)	0.033	0.031	0.0642
PKE(m/s2)	0.161	0.157	0.0259
Total Deviation			**0.5211**
SSD			**0.03**

Figure 29: Driving cycle for southern expressway

6.3.4. Model Cycle Construction (DCC2014)

Introduction

Model Cycle construction is one of the major methods used to develop driving cycles all around the world. It captures the mode changes in the driving and then develop the cycle proportionate to the percentage of driving.

The new methodology was developed to capture the driving modes and mode changes.

First the states were defined as mentioned previously (Table 2) according to acceleration and speed classes and using the software percentages of states were calculated.

Table 18: Probabilities of each state

State	Time Probability
0	0.176268352
1	0.060970747
2	0.020703
3	0.003203141
4	0.000356948
5	0.11575457
6	0.100274287
7	0.022863477
8	0.002207443
9	0.052236563
10	0.058013489
11	0.015029401
12	0.001315073
13	0.132221158
14	0.134513141
15	0.031975051
16	0.003456762
17	0.041894456
18	0.022685003
19	0.003654023
20	0.000403915

Then the probability of state changes were calculated using software. The probability of state changes were assigned in to a matrix and it is given in table 19.

Table 19: Probability of state changes

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.656	0	0	0	0.342	0.002	0	0
1	0.114	0	0	0	0	0.598	0	0	0	0.095	3E-04	0	0	0.138	0.011	0	0	0.031	0.012	7E-04	0
2	0.002	0	0	0	0	0.205	0.488	0	0	0.018	0.085	0	0	0.009	0.153	0.008	0	0.002	0.028	0.002	0
3	0	0	0	0	0	0	0.242	0.437	0	0	0.005	0.065	0	0	0.014	0.191	0	0	0	0.033	0.014
4	0	0	0	0	0	0	0	0.32	0.4	0	0	0.04	0.08	0	0	0	0.16	0	0	0	0
5	0.067	0.205	0	0	0	0	0	0	0	0.261	2E-04	0	0	0.37	0.034	0	0	0.049	0.013	2E-04	0
6	2E-04	0.137	0.129	0	0	0	0	0	0	0.012	0.299	7E-04	0	0.002	0.372	0.017	0	7E-04	0.031	0.001	0
7	0	0.016	0.137	0.101	0	0	0	0	0	0	0.023	0.314	8E-04	0	0.005	0.367	0.008	0	0	0.023	0.003
8	0	0	0.017	0.171	0.162	0	0	0	0	0	0	0.06	0.231	0	0	0.009	0.325	0	0	0	0.026
9	0.032	0.043	0	0	0	0.377	0	0	0	0	0	0	0	0.426	0.055	0	0	0.053	0.014	0	0
10	2E-04	0.023	0.028	0	0	0.036	0.434	0	0	0	0	0	0	0	0.421	0.027	0	0	0.028	0.002	0
11	0	9E-04	0.025	0.02	0	0	0.106	0.395	0	0	0	0	0	0	0	0.415	0.017	0	0	0.018	0.004
12	0	0	0	0	0	0	0	0.198	0.267	0	0	0	0	0	0	0	0.515	0	0	0	0.02
13	0.017	0.043	0	0	0	0.331	0.007	0	0	0.287	0.013	0	0	0	0	0	0	0.234	0.068	6E-04	0
14	0	0.023	0.034	2E-04	0	0.03	0.395	0.004	0	7E-04	0.377	0.015	0	0	0	0	0	0	0.108	0.014	0
15	0	0.001	0.016	0.02	7E-04	0	0.06	0.399	0.004	0	0.002	0.402	0.005	0	0	0	0	0	0	0.082	0.008
16	0	0	0	0.058	0.026	0	0	0.071	0.397	0	0	0	0.365	0	0	0	0	0	0	0	0.083
17	0.004	0.023	4E-04	0	0	0.12	0.005	0	0	0.087	0.012	0	0	0.575	0.173	8E-04	0	0	0	0	0
18	0	0.009	0.029	0	0	0.01	0.15	0.001	0	6E-04	0.113	0.004	0	0	0.618	0.065	0	0	0	0	0
19	0	0.004	0.018	0.018	0	0	0.028	0.208	0.007	0	0.004	0.106	0	0	0	0.556	0.053	0	0	0	0
20	0	0	0.025	0.05	0.025	0	0	0.025	0.25	0	0	0	0.175	0	0	0	0.45	0	0	0	0

After calculating state probabilities (in table 18) the time required from each state to develop a 1200s driving cycle is calculated and shown in table 20. The probabilities are recalculated using equation 4 and the method is shown in table 9.

Table 20: Time required form each state for 1200s driving cycle

State	Time Probability	Time allocated in driving cycle (s)
0	0.176268352	212
1	0.060970747	73
2	0.020703	25
3	0.003203141	4
4	0.000356948	0
5	0.11575457	139
6	0.100274287	120
7	0.022863477	27
8	0.002207443	3
9	0.052236563	63
10	0.058013489	70
11	0.015029401	18
12	0.001315073	2
13	0.132221158	159
14	0.134513141	161
15	0.031975051	38
16	0.003456762	4
17	0.041894456	50
18	0.022685003	27
19	0.003654023	4
20	0.000403915	0

After developing the State occurrence probability table and State changes matrix (described in table 9) the new matrix is introduced by multiplying the state changes matrix by state probabilities. New matrix for probabilities to select modes is given in table 21.

And then the cycle starts from idling state and from idling state is selected where the maximum probability occur and it is shown in table 21. Then the data set was selected from the corresponding state and the size of sample is deduct from data available from corresponding step. Recalculate the state probabilities using equation 4 hence recalculate new probabilities for state changes.

Table 21: New Probabilities for state changes

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.086794	0	0	0	0.014313	4.35413E-05	0	0
1	0.020142	0	0	0	0	0.069223	0	0	0	0.00495	1.98E-05	0	0	0.018184	0.001519	0	0	0.001319	0.00027163	2.5E-06	0
2	0.000404	0	0	0	0	0.023769	0.011152	0	0	0.000917	0.004916	0	0	0.001211	0.020536	0.000244	0	9.59E-05	0.000640721	8.37E-06	0
3	0	0	0	0	0	0	0.00553	0.009996	0	0	0.00027	0.000979	0	0	0.001877	0.006098	0	0	0	0.000119	5.64E-06
4	0	0	0	0	0	0	0	0.007316	0.000883	0	0	0.000601	0.000105	0	0	0	0.000553	0	0	0	0
5	0.011889	0.012513	0	0	0	0	0	0	0	0.013656	8.83E-06	0	0	0.048878	0.004567	0	0	0.00206	0.000290125	5.56E-07	0
6	3.22E-05	0.008364	0.002662	0	0	0	0	0	0	0.000619	0.017334	1.1E-05	0	0.000217	0.049982	0.000531	0	3.06E-05	0.000695199	5.33E-06	0
7	0	0.00098	0.002846	0.000324	0	0	0	0	0	0	0.001352	0.004724	1.06E-06	0	0.000649	0.011746	2.78E-05	0	0	8.52E-05	1.3E-06
8	0	0	0.000354	0.000548	5.8E-05	0	0	0	0	0	0	0.000899	0.000303	0	0	0.000273	0.001123	0	0	0	1.04E-05
9	0.0056	0.002619	0	0	0	0.043668	0	0	0	0	0	0	0	0.056335	0.007384	0	0	0.002202	0.00031794	0	0
10	4.04E-05	0.001426	0.000189	0	0	0.004221	0.009916	0	0	0	0	0	0	0	0.056613	0.000858	0	0	0.00064517	5.87E-06	0
11	0	5.42E-05	0.000516	6.55E-05	0	0	0.002421	0.009031	0	0	0	0	0	0	0	0.013257	5.84E-05	0	0	6.5E-05	1.44E-06
12	0	0	0	0	0	0	0	0.004527	0.00059	0	0	0	0	0	0	0	0.00178	0	0	0	8E-06
13	0.002956	0.00265	0	0	0	0.038304	0.000157	0	0	0.014985	0.000761	0	0	0	0	0	0	0.009788	0.001538359	2.13E-06	0
14	0	0.001396	0.000697	5.31E-07	0	0.003419	0.00904	0.000102	0	3.47E-05	0.02186	0.000222	0	0	0	0	0	0	0.002442769	5.09E-05	0
15	0	8.42E-05	0.000329	6.42E-05	2.47E-07	0	0.001374	0.009126	9.15E-06	0	0.00012	0.006041	6.36E-06	0	0	0	0	0	0	0.0003	3.07E-06
16	0	0	0	0.000185	9.15E-06	0	0	0.001612	0.000877	0	0	0	0.000181	0	0	0	0	0	0	0	3.37E-05
17	0.000677	0.001428	7.95E-06	0	0	0.013908	0.000114	0	0	0.004552	0.000668	0	0	0.076034	0.023236	2.45E-05	0	0	0	0	0
18	0	0.000563	0.000599	0	0	0.001212	0.003421	2.82E-05	0	3.22E-05	0.006573	5.55E-05	0	0	0.08316	0.002067	0	0	0	0	0
19	0	0.000215	0.000364	1.64E-05	0	0	0.000644	0.00475	1.55E-05	0	0.000204	0.001588	0	0	0	0.017789	0.000183	0	0	0	0
20	0	0	0.000518	0.00016	8.92E-06	0	0	0.000572	0.000552	0	0	0	0.00023	0	0	0	0.001556	0	0	0	0

Table 22: Step2_New probabilities for state changes

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.084411	0	0	0	0.014373	4.37235E-05	0	0
1	0.020226	0	0	0	0	0.069513	0	0	0	0.004971	1.99E-05	0	0	0.017685	0.001525	0	0	0.001324	0.000272767	2.51E-06	0
2	0.000405	0	0	0	0	0.023869	0.011199	0	0	0.000921	0.004936	0	0	0.001178	0.020622	0.000245	0	9.63E-05	0.000613402	8.4E-06	0
3	0	0	0	0	0	0	0.005553	0.010038	0	0	0.000271	0.000023	0	0	0.001885	0.006123	0	0	0	0.000119	5.66E-06
4	0	0	0	0	0	0	0	0.007347	0.000887	0	0	0.000604	0.000106	0	0	0	0.000555	0	0	0	0
5	0.011939	0.012566	0	0	0	0	0	0	0	0.013713	8.87E-06	0	0	0.047536	0.004586	0	0	0.002069	0.000291339	5.59E-07	0
6	3.23E-05	0.008399	0.002674	0	0	0	0	0	0	0.000623	0.017407	1.1E-05	0	0.000211	0.050191	0.000533	0	3.07E-05	0.000698108	5.35E-06	0
7	0	0.000984	0.002858	0.000326	0	0	0	0	0	0	0.001358	0.000144	1.06E-06	0	0.000651	0.011796	2.79E-05	0	0	8.55E-05	1.3E-06
8	0	0	0.000355	0.00055	5.82E-05	0	0	0	[illegible]	0	0	0.000903	0.000305	0	0	0.000274	0.001127	0	0	0	1.04E-05
9	0.005623	0.00266	0	0	0	0.043851	0	0	0	0	0	0	0	0.054788	0.007415	0	0	0.002211	0.00031927	0	0
10	4.06E-05	0.001432	0.000591	0	0	0.004239	0.009958	0	[illegible]	[illegible]	0	0	0	0	0.05685	0.000862	0	0	0.000647869	5.89E-06	0
11	0	5.45E-05	0.000518	6.58E-05	0	0	0.002431	0.009065	0	[illegible]	0	0	0	0	0	0.013312	5.87E-05	0	0	6.53E-05	1.44E-06
12	0	0	0	0	0	0	[illegible]	0.004546	0.000593	0	0	0	0	0	0	0	0.001787	0	0	0	8.03E-06
13	0.002969	0.002661	0	0	0	0.038464	0.000157	0	0	0.015047	0.000765	0	0	0	0	0	0	0.009829	0.001544795	2.14E-06	0
14	0	0.001402	0.0007	5.34E-07	0	0.003433	0.009078	0.000103	0	3.48E-05	0.021951	0.000223	0	0	0	0	0	0	0.002452989	5.11E-05	0
15	0	8.46E-05	0.00033	6.44E-05	2.48E-07	0	0.001379	0.009165	9.19E-06	0	0.000121	0.006066	6.38E-06	0	0	0	0	0	0	0.000302	3.08E-06
16	0	0	0	0.000186	9.19E-06	0	0	0.001619	0.000881	0	0	0	0.000483	0	0	0	0	0	0	0	3.38E-05
17	0.000679	0.001434	7.98E-06	0	0	0.013967	0.000115	0	0	0.004571	0.000671	0	0	0.073946	0.023334	2.47E-05	0	0	0	0	0
18	0	0.000566	0.000602	0	0	0.001217	0.003435	2.83E-05	0	3.23E-05	0.0066	5.58E-05	0	0	0.083508	0.002076	0	0	0	0	0
19	0	0.000216	0.000366	5.66E-05	0	0	0.000647	0.00477	1.56E-05	0	0.000205	0.001594	0	0	0	0.017863	0.000183	0	0	0	0
20	0	0	0.00052	0.000161	8.96E-06	0	0	0.000574	0.000554	0	0	0	0.000231	0	0	0	0.001562	0	0	0	0

1

2

Likewise in each step new proportions are calculated for states using equation 4 the method shown in table 9 and new probabilities for state changes are calculated. And the state is selected where the maximum probability of occurred for corresponding state.

I. After reaching for 1200s data cycle stops. Software gives mainly five types of outputs.
II. Analysis of population parameters with candidate cycles
III. Initial probability of state changes matrix
IV. State occurrence probability
V. Candidate cycle speed lists
VI. Images of candidate cycles

Using DCC2014 software 100 driving cycles were constructed and selected 10 for further Analysis. Then selected the driving cycle where the deviation proportion is less.

	Population	Parameters	Proportion of Deviation
Average Speed (km/h)	21.29	20.26	0.048
Average Running Speed (km/h)	27.21	28.82	0.059
Average Acceleration (m/s2)	0.2	0.23	0.15
Average Deceleration (m/s2)	-0.2	-0.22	0.1
Time Proportion for Idling	20.62	20.5	0.005
Time Proportion for cruising	12	12.75	0.063
Time Proportion for acceleration	35.83	36.1	0.008
Time Proportion for Deceleration	31.53	30.65	0.028
RMS (m/s2)	0.8	0.6	0.25
PKE (m/s2)	0.47	0.57	0.213
PV			0.924

The graphical representation of the selected cycle is shown in figure 30.

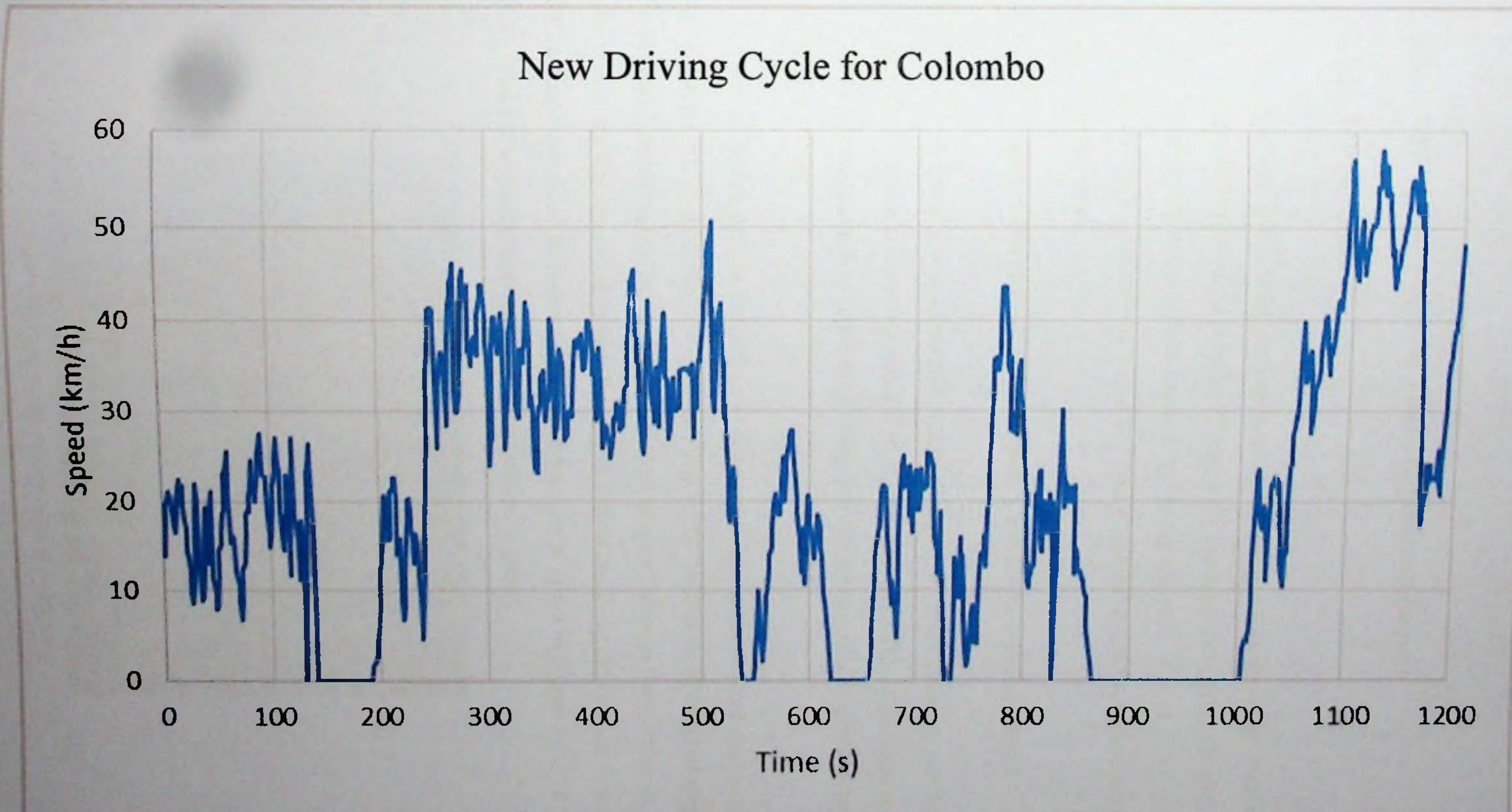


Figure 30: Colombo Driving Cycle (New Approach)

6.4. Cycle Construction for Traffic Engineering Purpose

6.4.1. Introduction

Driving Cycle for Traffic Engineering purpose has to represent the exact location of the road where driving cycle is pointing. Therefore when constructing the driving cycle segment based cycle construction method has being adopted. The driving cycle is constructed using two parameters which are road length vs. speed to capture the speed profile along the road.

6.4.2. Segment based cycle construction: Case Study-Baseline Road

In the Segment based cycle construction, a trip "segment" is obtained by partitioning vehicle speed-time profiles using changes in roadway type or LOS, in addition to stops and it can be constructed to represent driving activity for specific roadway types and traffic conditions.

There the collected data is divided in to segment using traffic related parameters or other criteria which represent the homogeneous traffic behaviour in selected segment. To capture homogeneous traffic behaviour the segmentation was done between every junction in the baseline road (where there is an inflow traffic to the road or an outflow traffic from the road) Points used for segmentation is given in figure 31. 38 points were used for segmentation and 37 segments were obtained.

Figure 31: Points used for segmentation (Baseline road)

Methodology is given in chapter three was used and the segmentation was done using a software which is developed during the research to construct driving cycle.

KML file was prepared by including the point as shown in figure 32 and using the developed file and the software the segmentation was done for the collected data.

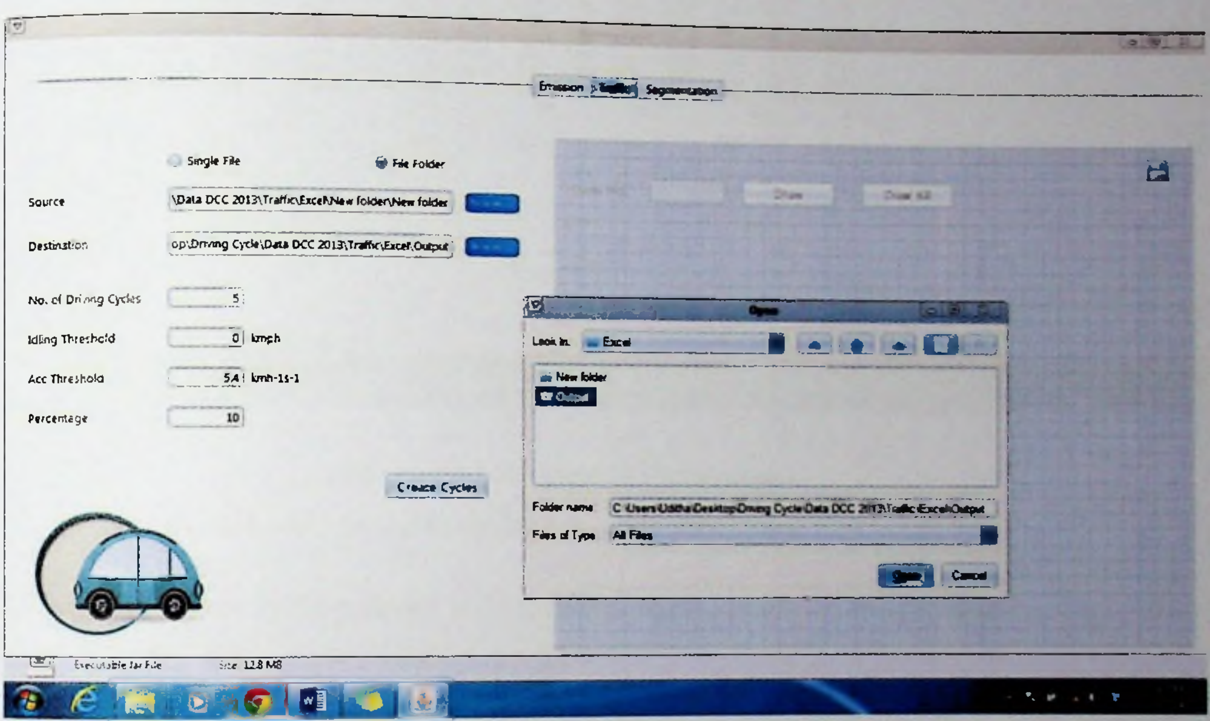


Figure 32: Software to develop driving cycle for traffic engineering purpose (DC2013)

When constructing cycles using software, two out puts were obtained as in micro trip based cycle construction.

3. Constructed candidate cycles with analysis
   Speed time list for candidate driving cycles and the analysis of candidate cycles with population are given as an output in excel format and sample is given in figure 33.

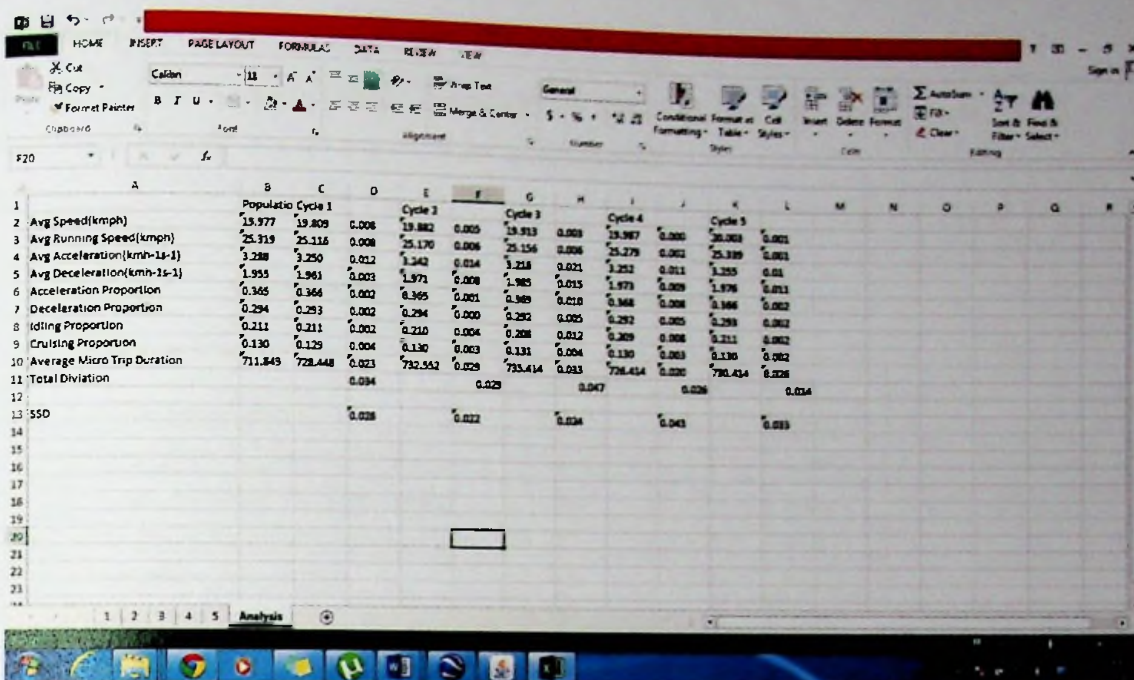


Figure 33: candidate speed lists with analysis

4. Graphs of constructed candidate cycles with cycle parameters

Other output given by the software is the graphical representation for the candidate driving cycles. A sample is given in figure 34.

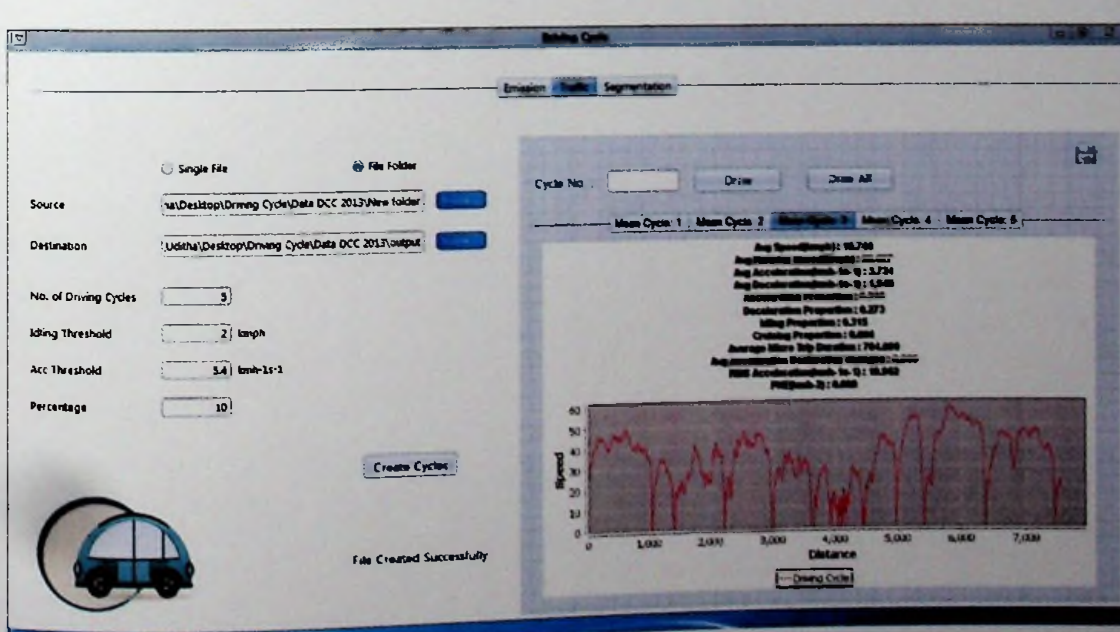


Figure 34: Graphical representation of candidate cycles

100 Candidate cycles were constructed and five driving cycles were selected which has lower PV (Performance Value). The results are shown in Appendix 8 and cycle number 5 was selected as a driving cycle for Baseline road.

Table 23: Parameters of driving cycle for baseline road

	Population	Cycle 5	
Average Speed (km/h)	19.977	20.003	0.001
Average Running Speed (km/h)	25.319	25.339	0.001
Average Acceleration (kmh-1s-1)	3.288	3.255	0.01
Average Deceleration (kmh-1s-1)	1.955	1.976	0.011
Acceleration Proportion	0.365	0.366	0.002
Deceleration Proportion	0.294	0.293	0.002
Idling Proportion	0.211	0.211	0.002
Cruising Proportion	0.130	0.130	0.002
Average Micro Trip Duration (s)	711.849	730.414	0.026
Total Deviation			0.014
SSD			0.033

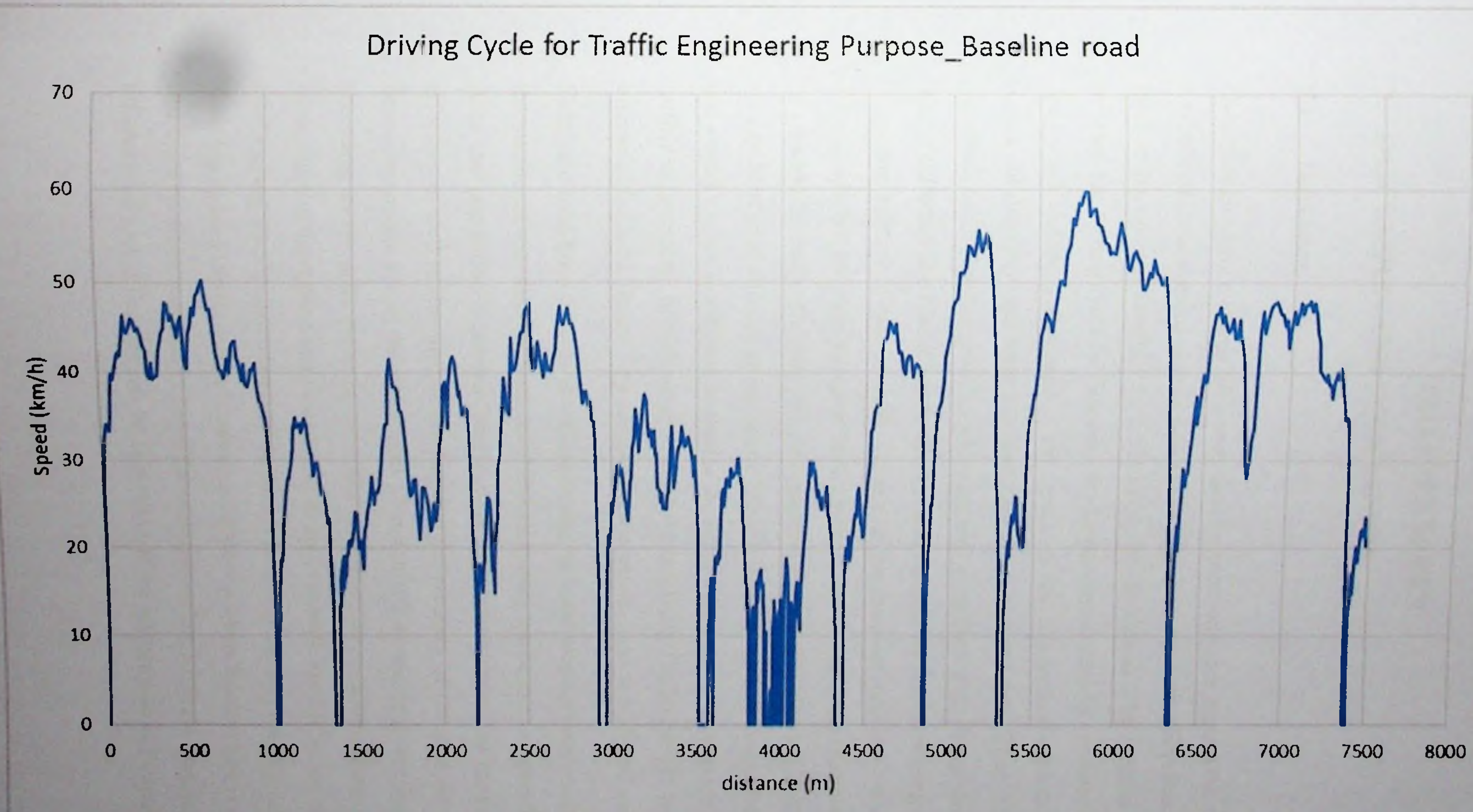


Figure 35: Selected traffic engineering driving cycle for baseline road

CHAPTER SEVEN

7. DISCUSSION AND CONCLUSION

7.1. Discussion

Even though many methods have been used for route selection around the world the methods have limitations such as data availability, cost, time etc. Therefore methods have to be selected carefully by considering the limitations. The method used for develop the driving cycle for Colombo, Sri Lanka was selected by considering above mentioned factors. Advantages of the method is that this method separately select routes for intercity and intra city and then combined together. Then links were generated using physical junctions where the road conditions were changed. Since the data is collected link wise it is cost effective and suitable for the developing countries where there is lack of data available. Other than that there are some draw backs in the method adopted for route selection. In this method cycle construction method have to be selected carefully. The data sets are segmented according to physical links the data set can be started and end at any speed, hence micro trip method cannot be adopted and model cycle construction method is the best method for cycle construction. For further improvement of the method Average Annual Daily Traffic have to be adopted instead of Daily traffic and Trip attractors and generates have to be found carefully.

Using the road links the data is collected using on board measurement method. Also the number of data samples were calculated using daily traffic in corresponding links. After that population is generated and used for cycle construction. The method is cost effective as well as less time consuming. But the accuracy of the data set is highly dependent on the size of the data sample. Therefore it is advisable to increase the size according to the daily travel in respective road links. Even though there are many advantages of the method there are some draw backs as well. Road links are used when synthesizing the population but consideration is not given whether the data link is from short trip or long trip (origin and destination of the trip where the data link is selected). But there could be variation in travel behaviour according to origin destination. The influence of such a data set can be minimized if the sample size is increased. Also when collecting data for the research vehicles were selected where the people who drove the vehicle are almost in same disciplinarians. But the behaviour can be varied according to the driver's characteristic such as age, gender, profession etc. Therefore it is necessary to pay attention to those parameters when collecting data.

As discussed in data collection method chase car method gives representative data set if it could use without any obstacle. For Colombo Driving Cycle hybrid method of chase car and on board measurement method can be used as data collection method. For urban areas on board measurement method can be used and for suburban area of Colombo chase car method can be used.

In chase car method the routes were selected prior to the data collection and then the vehicle is chased. If the vehicle changed the route from the pre-determined route, chasing terminated. But if the method is changed such that the few routes are selected where the AADT is high, then chase a vehicle until the vehicle covers two or three road categories (major and minor roads). It will minimize the efforts for route selection as well as gives more representative data set then in previously used chase car method.

In this research many methods have been adopted for developing driving cycles for many purposes. Micro trip method is adopted to develop driving cycle for emission purpose. This method is easy to adopt and seems realistic (It is constructed using actual trip segments on the road) but for the data collected used in Colombo cannot be used directly for this method. But if the data can be collected using whole route (not the links) this method is fast and easy method to adopt.

Segment based cycle construction method was used to develop an emission driving cycle for expressways where there is no any idle time in between origin and destination. The accuracy of the method is strictly depend on the number of points for segmentation but then the analysis get complexes. Also the method is used to develop driving cycle for traffic engineering purpose and the accuracy of the driving cycle is highly depend on the number of points for segmentation. But it is difficult to analyse the data set if number of points are more. Further improvement can be done to develop a dynamic driving cycle for traffic engineering purpose combined with ITS. Hence predict a traffic time, shortest travel time path for a trip, where the traffic congestion is etc.

Modal cycle construction was adopted as a new method of cycle construction for Colombo. The results of the new approach doesn't seem realistic. But considering the population it gives the driving mode which could be occurred after current state of driving. When selecting the data segments Speed Acceleration Frequency Distribution is considered. Therefore after constructing the cycle SSD is not calculated. Also for the adopted data collection method modal cycle construction method fits best. But for the regions where there is less variation this method will not be suitable. Also for the short length driving cycles the method will not be suitable. The accuracy of the cycle constructed using this method is highly depend on the size of the data set.

Cycle assessment is crucial for the representativeness of the developed cycle for collected data population. Parameters vary according to the purpose of the driving cycle. For Emission Purpose in micro trip method 11 parameters have been used. Since the points for segmentation are defined by manually "Average micro trip duration" was not used in segment based cycle construction and other 10 parameters which are used in micro trip construction method have been used. In both cases (micro trip and segment based) PV value is used and SSD is used to further analysis. In new approach (modal cycle construction) 10 parameters have been used same as in segment based cycle construction method. But there SSD is not used since it is used for data selection criteria. PV value is used to assess the developed candidate cycle with population parameters.

For Traffic Engineering Purpose in segment based cycle construction nine parameters have been used for evaluate traffic engineering cycle which are used to evaluate the emission cycle using micro trip based cycle construction except PKE and RMS. There SSD is used to evaluate the best cycle from the cycle selected using lower PV value.

Comparison has been done to evaluate the parameters of driving cycles developed around the world. New comparison have been done to evaluate the performance of Southern expressway and parameters of developed cycle was compared with the cycle developed for expressways in Europe. Table 24 compares the parameters of developed driving cycles for expressways around the world.

Table 24: European Driving Cycles for freeways with Southern expressway driving cycle

No	Name of the Cycle	PKE (m/s2)	Average Speed (km/h)	Average Running Speed (km/h)	Max Speed (km/h)	% of cruise	% of Acceleration	% of Deceleration	Rms (m/s2)
1	Handbook_SI_incl_pre	1.784	107.3	107.33	131.2	38.4	32.97	28.63	0.038
2	Handbook_CI_incl_pre	2.006	108.2	108.72	131.1	32.4	34.13	33	0.04
3	Modem_IM_Motorway	2.847	101	102.37	128.26	23.1	39.6	36.06	0.087
4	INRETS aoutoroutes 2	2.65	94.5	94.7	131.5	28.15	41.13	30.53	0.084
5	LDV_PVU Commercial cars_motorway_2_total	2.551	89.7	93.16	140.52	25.29	38.63	31.98	0.094
6	LDV_PVU light vans_Empty_motorway_total	3.485	81.1	81.98	117.95	17.33	42.64	38.9	0.114
7	LDV_PVU_2.5t vans_Empty_motorway_total	2.553	90.2	90.92	122.76	28.1	37.06	34.07	0.08
8	LDV_PVU_2.8t vans_loaded_motorway_total	2.108	82.7	86.01	123.42	36.06	33.22	26.88	0.093
9	LDV_PVU_3.5t vans_motorway_total	2.111	88.1	89.51	130.44	33.67	44.06	20.7	0.082
10	M25 Highspeed Cycle	2.859	101.4	102.09	146.78	22.8	40.43	36.09	0.063
11	TRL_WSL motorwat 90	0.836	93.4	93.41	98.86	56.68	20.28	23.13	0.018
12	TRL_WSL motorwat 113	0.995	112.1	112.1	118.2	50	22.27	27.73	0.02
13	Artemis mw_150_incl_pre_post	2.955	99.6	100.35	150.37	27.81	39.7	31.74	0.092
14	Artemis mw_130_incl_pre_post	3.014	96.9	97.6	131.43	26.03	40.64	32.58	0.093
15	Artemis LowMot_motorway_total	2.862	97.7	99.03	150.32	26.32	42.58	29.79	0.092
16	Artemis HighMot_motorway_total	2.964	102.1	103.28	156.87	24.6	41.41	32.86	0.0082
17	EMPA BAB	1.805	117.5	117.53	160.83	35.6	38	26.4	0.027
18	EMPA C-2	2.088	75.3	76.11	88.37	31.88	33.7	33.33	0.052
19	EMPA C-3	1.566	115.3	116.17	127.14	46.08	27.95	25.26	1.566
20	EMPA C-6	2.423	103.4	107.63	127.2	34.9	31.06	30.1	0.09
21	EMPA EL1	1.794	101.7	102.29	127.2	35.1	31.43	32.9	0.039
22	EMPA T100	1.256	100	100.03	107.32	41.1	31.33	27.57	0.023
23	EMPA T115	1.022	115	115.01	122.44	49.37	26.07	24.56	0.019
24	EMPA T130	0.999	130	130	137.72	54.14	26.07	19.8	0.016
25	SE_Light_Veh_SL	0.1354	80.645	80.645	99.985	55.9	21	23.1	0.037

(Barlows. 2009)

For the analysis purpose some parameters have been taken in to consideration and using those parameters behaviour of the driving in expressways were compared with Southern Expressway. The parameters used for evaluating performance were

- Positive Kinetic Energy
- Root Mean Square Acceleration
- Average Speed
- Average Running Speed
- Max Speed
- %Cruising
- %of Acceleration
- %of Deceleration

Where RMS and PKE are given as in below equation

Root mean square acceleration (arms)

$$RMS=\sqrt[2]{\frac{1}{T}\left(\int_0^T a^2 dt\right)}$$

Positive kinetic energy (PKE).

$$PKE=\frac{1}{dist}\sum_{i=2}^{n}\{v_i^2 - v_{i-1}^2\}$$

$(where\ v_i > v_{i-1})$ Else 0

Average speed and average running speed implies the overall condition of the road and the time taken for a journey. Maximum speed implies the best condition of the road and using % time for acceleration, deceleration and cruising implies the driving behaviour and the of the driver on the road and further the driving behaviour is represented by the RMS and PKE and those parameters represent how smooth or how aggressive is the driver.

Considering other European driving cycles for freeways SE_Light_Veh_SL driving cycle has lower values (in the range of 75 to 90 km/h) for average speed and the average running speed of the vehicle fleet where most of the European cycles have a range of 100 to 130 km/h. Also SE_Light_Veh_SL driving cycle has a maximum speed of 99.985 km/h were most European driving cycles have more than 100km/h and some of the driving cycles have a maximum speed in the range of 140 to 160 km/h. When analysing time proportions for acceleration, deceleration and cruising SE_Light_Veh_SL driving cycle has high cruising time proportion which is more than 50% and lower acceleration and deceleration time proportions compared to other driving cycles developed for expressways.

Among those driving cycles SE_Light_Veh_SL driving cycle has the lowest PKE value and lower RMS value of 0.037 m/s^2.

7.2. Conclusion

Route selection method has to be improved further by using AADT for links, roughness of the road, elevation, gradient and weather condition. For the data collection combined method should be used by modifying the existing chase car method. Also attention must be given for the drivers' characteristics and the vehicle age as well. Furthermore if GPS devices can be insert in few vehicles then data can be collected continuously without influencing the driving pattern of the driver. Then driving cycle can be updated using data collected with those GPS devices.

Compared to parameters of the driving cycle developed in other regions still the traffic behaviour and the mobility of the traffic flow is high in urban areas in Sri Lanka (table 3). However when dividing collected data using physical points on the road (in segment based cycle construction) LOS, number of lanes, roughness and land use pattern should be considered along with physical junctions. Because sometimes between physical junctions the traffic related parameters or road parameters can be changed hence it will affect the traffic flow characteristics.

In Southern Expressway by comparing the selected parameters it can be seen that the average road condition is not very much better as in many European countries. Also the maximum speed is very much low compared to other cycles. But the proportions of cruising is more than 50% and acceleration deceleration proportions are below 25%. Therefore it can be conclude that the condition of the expressway is comparatively higher as many expressways around the world. Also the driving behaviour of the drivers on the expressway is smoother than all the driving cycles considered (Low PKE value)

Finally it can be conclude that the micro trip based cycle construction and Modal cycle construction methods are suitable for developing emission related and fuel economy driving cycles for Colombo city. Segment based cycle construction is better for developing traffic engineering driving cycles and emission and fuel economy driving cycles for express ways where there are less stop go conditions.

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APPENDICES

Appendix 1: Initial Routes identified for intercity trips using OD data

OD location	Route
Gamsabha Junction	Dehiwala_Nugegoda
	Nugegoda_Maharagama
	Nugegoda_Nugegoda
Piliyandala	Dehiwala_Kesbewa
	Moratuwa_Homagama
	Moratuwa_Kaduwela
	Moratuwa_Kesbewa
	Moratuwa_Maharagama
Matakkuliya	Gampaha_Bambalapitiya
	Gampaha_Dehiwala
	Gampaha_Fort
	Gampaha_Kolonnawa
	Gampaha_Kotahena
	Gampaha_Maradana
	Gampaha_Mattakkuliya
	Gampaha_Modera
	Gampaha_Pettah
Rajagiriya	Kaduwela_Nugegoda
	Kaduwela_Bambalapitiya
	Kaduwela_Borella
	Kaduwela_Fort
	Kaduwela_Kolllupitiya
	Kaduwela_Pettah
	Nugegoda_Pettah
Kohuwela	Dehiwala_Bambalapitiya
	Dehiwala_Borella
	Dehiwala_Fort
	Dehiwala_Pettah
	Dehiwala_Wellawatte
	Kesbewa_Bambalapitiya
	Kesbewa_Borella
	Kesbewa_Fort
	Kesbewa_Pettah
	Nugegoda_Borella
	Nugegoda_Fort
	Nugegoda_Pamankada
	Nugegoda_Pettah
Highlevel	Dehiwala_Kirulapona
	Kesbewa_Narahenpita
	Nugegoda_Kirulapona
	Nugegoda_Kollupitiya
	Nugegoda_Narahenpita
	Nugegoda_Pettah
	Nugegoda_Thimbirigasyaya
Dehiwela	Dehiwala_Kollupitiya
	Dehiwala_Wellawatte
Kelanithissa	Gampaha_Pettah
Grandpass	Aluthkade_Borella
	Aluthkade_Kollupitiya
	Aluthkade_Wellawatte
	Gampaha_Dehiwala
	Gampaha_Fort
	Gampaha_Kolonnawa
	Gampaha_Kotahena
	Gampaha_Maradana
	Gampaha_Mattakkuliya
	Gampaha_Pettah

Appendix 2: Selected routes for intercity trips

OD location	Route
Gamsabha Junction	Nugegoda_Maharagama
	Nugegoda_Nugegoda
Piliyandala	Dehiwala_Kesbewa
	Moratuwa_Kesbewa
	Moratuwa_Maharagama
Matakkuliya	Gampaha_Bambalapitiya
	Gampaha_Dehiwala
	Gampaha_Fort
	Gampaha_Kotahena
	Gampaha_Mattakkuliya
	Gampaha_Pettah
Rajagiriya	Kaduwela_Nugegoda
	Kaduwela_Bambalapitiya
	Kaduwela_Fort
	Kaduwela_Pettah
	Nugegoda_Pettah
Kohuwela	Dehiwala_Bambalapitiya
	Dehiwala_Borella
	Dehiwala_Pettah
	Dehiwala_Wellawatte
	Kesbewa_Bambalapitiya
	Kesbewa_Fort
	Kesbewa_Pettah
	Nugegoda_Borella
	Nugegoda_Fort
	Nugegoda_Pettah
Highlevel	Dehiwala_Kirulapona
	Kesbewa_Narahenpita
	Nugegoda_Kirulapona
	Nugegoda_Narahenpita
	Nugegoda_Pettah
	Nugegoda_Thimbirigasyaya
Dehiwela	Dehiwala_Kollupitiya
Kelanithissa	Gampaha_Pettah
GrandPass	Aluthkade_Kollupitiya
	Gampaha_Dehiwala
	Gampaha_Fort
	Gampaha_Kotahena
	Gampaha_Pettah

Appendix 3: Routes selected for intra city trips

1	N.M Ishak Road
2	Arawwala Road
3	Aththidiya Road
4	Athurugiriya Kottawa Road
5	Athurugiriya Road
6	Awissawella Road
7	Baseline
8	Bauddaloka Mawatha
9	Borella KOttawa Road
10	Buthgamuwa Road
11	Castle Street
12	Chiththampalam Gardiner Mawatha
13	Colombo Horana Road B4
14	D.R Wijewardane Mawatha
15	Dehiwela Maharagama Road
16	Ernest De Silva and Kumarathungamunidasa Mawatha
17	Gall Road
18	Gnanartha Pradeepa Mawatha
19	Godagama Kottawa
20	Haban Hina watte Road
21	Havlock and Dutugamunu Road
22	High Level
23	Hokandara Thalawathugoda Road
24	Hospital Road
25	Jeorge R De Silva and Sumanathissa mawatha
26	Justice Akbar Mawatha
27	Kaduwela Road
28	Kahathuduwa Diyagama Road
29	Kesbewa KOsgahahandiya Road

30	Kolonnawa Angoda Road
31	Kolonnawa Road
32	Koswatte Road
33	Kottawa Horana Road
34	Kotte Road
35	Kumaran Rathanam Mawatha
36	Lotus Road
37	Lower Chathem Street
38	Makey Street
39	Makuluduwa Road
40	Malabe Kottawa Road
41	Malapalla and Densil Kobbakaduwa Road Homagama
42	Mattakkuliya central Road
43	N.H.M Abdul Cader Road
44	Nawala Road
45	New Kandy Road
46	Olcutt and Sangaraja Mawatha
47	Old Kottawa Road
48	Pagoda Road
49	Panchikawatta Road
50	Pannipitiya Malabe Road
51	Pathiragoda and Polwatta road
52	Pepiliyana Road
53	Piliyandala Maharagama Road
54	Pitakotte_Thalawathugoda Road
55	Pitipana THalawathugoda Road
56	R.A De Mel Mawatha
57	Rathmalana Mirihana Road
58	Rifle Street

59	S De S Jayasinghe Road
60	Sedawatta Ambathale Road
61	Sir Baron Jayathilaka Mawatha
62	Sri James Peris Mawatha
63	Sri Jayawardanapura Mawatha
64	Sri Saddharma Mawatha
65	Sri Sambuddathava Jayanthi Mawatha
66	Sri Uttarananda Road and R.A De Mel Mawatha
67	Srimath Anagarika Darmapala and E.W Perera Mawatha
68	Srimath Anagarika Darmapala mawatha
69	Stanley THilakarathna Mawatha
70	T.B. Jaya Mawatha
71	Thimbirigasyaya Road
72	Wanaguru Road

Appendix 4: Route links for synthesize road map for data collection

LinkNo	Name
1	Moratuwa_Katubedda
2	Katubedda_Rathmalana
3	Ratmalana_Dehiwela
4	Dehiwela_Wellawatta
5	Wellawatta_Bambalapitiya
6	Bambalapitiya_Kollupitiya
7	Kollupitiya_Gallface
8	GallFace_PresidentialSecretorial
9	Lotus Road
10	Lower Chathem Street
11	Sir Baron Jayathilaka Mawatha
12	R.A De Mel Mawatha 1
13	R.A De Mel Mawatha 1
15	Makey Street
14	Sri Uttarananda Road and R.A De Mel Mawatha
16	Justice Akbar Mawatha
17	Rifle Street
18	Chiththampalam Gardiner Mawatha
19	D.R Wijewardane Mawatha
20	T.B. Jaya Mawatha
21	Panchikawatta Road
22	Olcutt and Sangaraja Mawatha
23	Jeorge R De Silva and Sumanathissa mawatha
24	N.H.M Abdul Cader Road
25	Kumaran Rathanam Mawatha
26	Sri James Peris Mawatha
27	Srimath Anagarika Darmapala mawatha
28	Srimath Anagarika Darmapala and E.W Perera Mawatha
29	Gnanartha Pradeepa Mawatha
30	N.M Ishak Road

31	Baseline 1
32	Baseline 2
33	Baseline 3
34	Baseline 4
35	Bauddaloka Mawatha
36	Ernest De Silva and Kumarathungamunidasa Mawatha
37	Sri Sambuddathava Jayanthi Mawatha
39	Thimbirigasyaya Road
40	Sri Saddharma Mawatha
41	Hospital Road
42	Havlock and Dutugamunu Road
43	S De S Jayasinghe Road
44	High Level 1
45	High Level 2
46	High Level 3
47	High Level 4
48	High Level 5
49	High Level 6
50	Colombo Horana Road B4 1
51	Colombo Horana Road B4 2
52	Colombo Horana Road B4 3
53	Colombo Horana Road B4 4
54	Colombo Horana Road B4 5
55	Dehiwela Maharagama Road 1
56	Dehiwela Maharagama Road 2
57	Dehiwela Maharagama Road 3
58	Pepiliyana Road 1
65	Makuluduwa Road
66	Kesbewa KOsgahahandiya Road
67	Arawwala Road
68	Kahathuduwa Diyagama Road
69	Kottawa Horana Road

72	Sri Jayawardanapura Mawatha
70	Castle Street 1
71	Castle Street 2
62	Piliyandala Maharagama Road 1
63	Piliyandala Maharagama Road 2
64	Piliyandala Maharagama Road 3
59	Pepiliyana Road 2
60	Aththidiya Road 1
61	Aththidiya Road 2
73	Kaduwela Road 1
74	Kaduwela Road 2
75	Kaduwela Road 3
76	Athurugiriya Road
77	Gadagama Kottawa
78	Gadagama Kottawa
79	Nawala Road 1
80	Nawala Road 2
81	Nawala Road 3
82	Stanley THilakarathna Mawatha
83	Pagoda Road
84	Rathmalana Mirihana Road
85	Kotte Road
86	Old Kottawa Road
87	Pitakotte_Thalawathugoda Road
87	Pathiragoda and Polwatta road
88	Borella KOttawa Road 1
89	Borella KOttawa Road 2
90	Pannipitiya Malabe Road
91	Malabe Kottawa Road 1
92	Malabe Kottawa Road 2

93	Hokandara Thalawathugoda Road
94	Wanaguru Road
96	Athurugiriya Kottawa Road 2
95	Athurugiriya Kottawa Road 1
97	Pitipana THalawathugoda Road
98	Malapalla and Densil Kobbakaduwa Road Homagama
99	Haban Hina watte Road
100	Mattakkuliya central Road
101	Sedawatta Ambathale Road
102	Kotte Road
103	Awissawella Road 1
104	Awissawella Road 2
105	Awissawella Road 3
106	Kolonnawa Road
107	Kolonnawa Angoda Road 1
108	Kolonnawa Angoda Road 2
109	Buthgamuwa Road
110	Koswatte Road
111	New Kandy Road
112	ASP
113	A0
114	Olcutt Mawatha
116	A1
117	A1
118	Biyagama Road
119	A3
120	B1
121	255CampsRd

Appendix 5: Road links for each road group

Link No	Name
65	Makuluduwa Road
110	Koswatte Road
122	Pathiragoda and Polwatta road
98	Malapalla and Densil Kobbakaduwa Road Homagama
99	Haban Hina watte Road
14	Sri Uttarananda Road and R.A De Mel Mawatha
15	Makey Street
16	Justice Akbar Mawatha
17	Rifle Street
41	Hospital Road
24	N.H.M Abdul Cader Road
76	Athurugiriya Road
43	S De S Jayasinghe Road
92	Malabe Kottawa Road 2
93	Hokandara Thalawathugoda Road
94	Wanaguru Road
95	Athurugiriya Kottawa Road 1
96	Athurugiriya Kottawa Road 2
106	Kolonnawa Road
107	Kolonnawa Angoda Road 1
108	Kolonnawa Angoda Road 2
62	Piliyandala Maharagama Road 1
63	Piliyandala Maharagama Road 2
64	Piliyandala Maharagama Road 3
66	Kesbewa KOsgahahandiya Road
67	Arawwala Road
68	Kahathuduwa Diyagama Road
121	255CampsRoad
60	Aththidiya Road 1
61	Aththidiya Road 2
109	Buthgamuwa Road
30	N.M Ishak Road
39	Thimbirigasyaya Road
55	Dehiwela Maharagama Road 1
56	Dehiwela Maharagama Road 2
57	Dehiwela Maharagama Road 3
58	Pepiliyana Road 1
59	Pepiliyana Road 2
69	Kottawa Horana Road
84	Rathmalana Mirihana Road
86	Old Kottawa Road
91	Malabe Kottawa Road 1
119	Marine Drive

112	ASP
113	Nelumpokuna Mawatha
114	Olcott Mawatha
90	Pannipitiya Malabe Road
100	Mattakkuliya central Road
77	Godagama Kottawa
78	Godagama Kottawa
9	Lotus Road
10	Lower Chathem Street
11	Sir Baron Jayathilaka Mawatha
79	Nawala Road 1
80	Nawala Road 2
81	Nawala Road 3
82	Stanley THilakarathna Mawatha
83	Pagoda Road
85	Kotte Road
87	Pitakotte Thalawathugoda Road
88	Borella KOttawa Road 1
89	Borella KOttawa Road 2
35	Bauddaloka Mawatha
37	Sri Sambuddathava Jayanthi Mawatha
19	D.R Wijewardane Mawatha
28	Srimath Anagarika Darmapala and E.W Perera Mawatha
23	Jeorge R De Silva and Sumanathissa mawatha
102	Kotte Road
73	Kaduwela Road 1
74	Kaduwela Road 2
75	Kaduwela Road 3
97	Pitipana THalawathugoda Road
103	Awissawella Road 1
104	Awissawella Road 2
105	Awissawella Road 3
118	Biyagama Road
120	B1
20	T.B. Jaya Mawatha
21	Panchikawatta Road
29	Gnanartha Pradeepa Mawatha
48	High Level 5
49	High Level 6
50	Colombo Horana Road B4 1
51	Colombo Horana Road B4 2
52	Colombo Horana Road B4 3
53	Colombo Horana Road B4 4
54	Colombo Horana Road B4 5

22	Olcutt and Sangaraja Mawatha
44	High Level 1
45	HIgh Level 2
46	High Level 3
47	HIgh Level 4
40	Sri Saddharma Mawatha
1	Moratuwa_Katubedda
5	Wellawatta_Bambalapitiya
6	Bambalapitiya_Kollupitiya
7	Kollupitiya_Gallface
8	GallFace_PresidentialSecretorial
12	R.A De Mel Mawatha 1
13	R.A De Mel Mawatha 1
18	Chiththampalam Gardiner Mawatha
25	Kumaran Rathanam Mawatha
26	Sri James Peris Mawatha
36	Ernest De Silva and Kumarathungamunidasa Mawatha

31	Baseline 1
42	Havlock and [illegible] Road
32	Baseline 2
101	Sedawatta Ambathale Road
111	New Kandy Road
115	Negombo Road
27	[illegible]
2	[illegible]
3	[illegible]
4	Dehiwala_Wellawatta
70	Sri Jayawardenapura Mawatha 1
71	Sri Jayawardenapura Mawatha 2
72	Sri Jayawardenapura Mawatha
33	Baseline 3
34	Baseline 4
[illegible]	Colombo Kandy road
[illegible]	Colombo Kandy road

Appendix 6

(a) Parameters of candidate driving cycles (micro trip based cycle construction)

	Population	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Average Speed(km/h)	18.575	18.883	19.132	18.554	18.517	20.306	20.952	19.313	19.814	18.615	18.609
Average Running Speed (km/h)	23.725	23.703	24.142	21.924	20.689	24.294	25.067	23.868	25.241	26.849	22.175
Average Acceleration (m/s2)	0.206	0.222	0.258	0.231	0.248	0.217	0.258	0.192	0.226	0.183	0.2352
Average Deceleration(m/s2)	0.185	0.196	0.230	0.201	0.212	0.188	0.230	0.168	0.199	0.163	0.212
Acceleration Proportion	0.35	0.382	0.376	0.405	0.383	0.352	0.372	0.346	0.349	0.312	0.392
Deceleration Proportion	0.307	0.316	0.322	0.318	0.37	0.334	0.362	0.299	0.328	0.246	0.322
Idling Proportion	0.217	0.203	0.208	0.153	0.104	0.164	0.164	0.191	0.215	0.307	0.161
Cruising Proportion	0.126	0.099	0.094	0.124	0.142	0.149	0.102	0.164	0.108	0.135	0.125
RMS Acceleration(m/s2)	0.012	0.011	0.013	0.012	0.016	0.013	0.012	0.012	0.011	0.009	0.011
PKE(m/s2)	1.916	1.71	2.127	1.683	2.659	2.432	2.461	1.599	2.518	1.73	2.009

(b) Deviation of parameters of candidate driving cycle with population parameters(micro trip based cycle construction)

	Population	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Average Speed(km/h)	18.575	0.017	0.03	0.001	0.003	0.093	0.128	0.04	0.067	0.002	0.002
Average Running Speed (km/h)	23.725	0.001	0.018	0.076	0.128	0.024	0.057	0.006	0.064	0.132	0.065
Average Acceleration (m/s2)	0.206	0.013	0.164	0.033	0.098	0.047	0.175	0.058	0.099	0.007	0.018
Average Deceleration(m/s2)	0.185	0.025	0.184	0.047	0.049	0.067	0.052	0.068	0.005	0.098	0.089
Acceleration Proportion	0.35	0.091	0.074	0.157	0.096	0.007	0.065	0.012	0.002	0.107	0.119
Deceleration Proportion	0.307	0.029	0.05	0.034	0.205	0.088	0.178	0.026	0.067	0.199	0.05
Idling Proportion	0.217	0.063	0.044	0.294	0.52	0.244	0.244	0.121	0.01	0.413	0.259
Cruising Proportion	0.126	0.213	0.253	0.015	0.131	0.184	0.193	0.303	0.14	0.071	0.008
RMS Acceleration(m/s2)	0.012	0.107	0.11	0.122	0.388	0.269	0.284	0.166	0.314	0.097	0.048
PKE(m/s2)	0.449	0.049	0.231	0.002	0.094	0.087	0.176	0.106	0.098	0.059	0.081
Total Deviation		0.608	1.158	0.781	1.712	1.11	1.552	0.906	0.866	1.185	0.739
SSD		0.014	0.014	0.028	0.047	0.025	0.025	0.019	0.013	0.002	0.026

Appendix 7 (a): Candidate cycles for emission purpose (Segment based cycle construction)

	Population	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Average Speed(km/h)	80.315	83.942	85.078	79.382	80.645	85.588	81.905	86.588	81.475	75.638	84.131
Average Running Speed(km/h)	80.315	83.942	85.078	79.382	80.645	85.588	81.905	86.588	81.475	75.638	84.131
Average Acceleration(m/s2)	0.112	0.149	0.217	0.115	0.095	0.108	0.171	0.123	0.132	0.118	0.108
Average Deceleration(m/s2)	0.055	0.108	0.140	0.042	0.061	0.089	0.059	0.104	0.059	0.097	0.093
Acceleration Proportion	0.242	0.38	0.609	0.278	0.21	0.318	0.281	0.377	0.299	0.372	0.323
Deceleration Proportion	0.228	0.418	0.513	0.222	0.231	0.328	0.248	0.352	0.27	0.368	0.35
Idling Proportion	0	0	0	0	0	0	0	0	0	0	0
Cruising Proportion	0.53	0.202	0.123	0.501	0.559	0.355	0.471	0.271	0.431	0.261	0.327
RMS Acceleration(m/s2)	0.033	0.036	0.029	0.031	0.037	0.024	0.047	0.018	0.035	0.026	0.027
PKE(m/s2)	0.161	0.159	0.169	0.157	0.135	0.163	0.228	0.155	0.191	0.115	0.147

Appendix 7 (b): Analysis of candidate cycles for emission purpose (Segment based cycle construction)

	Population	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6	Cycle 7	Cycle 8	Cycle 9	Cycle 10
Average Speed(km/h)	80.315	0.0452	0.0567	0.0110	0.0042	0.0654	0.0186	0.0766	0.0134	0.0574	0.0505
Average Running Speed(km/h)	80.315	0.0452	0.0567	0.0110	0.0042	0.0654	0.0186	0.0766	0.0134	0.0574	0.0505
Average Acceleration(m/s2)	0.111723333	0.2878	0.7332	0.0132	0.1467	0.0445	0.5501	0.0632	0.1666	0.0499	0.0313
Average Deceleration(m/s2)	0.054656667	0.9735	0.7893	0.0893	0.1418	0.5667	0.0430	0.8459	0.0412	0.7219	0.3889
Acceleration Proportion	0.242	0.5702	0.9658	0.0591	0.1151	0.3619	0.1226	0.4804	0.1512	0.4348	0.2177
Deceleration Proportion	0.228	0.8333	0.6818	0.0117	0.0135	0.4329	0.0610	0.5	0.1193	0.5185	0.3315
Idling Proportion	0	0	0	0	0	0	0	0	0	0	0
Cruising Proportion	0.53	0.6189	2.0149	0.2358	0.0579	0.3131	0.1662	0.5499	0.3653	0.6241	0.7778
RMS Acceleration(m/s2)	0.033293866	0.0749	0.1313	0.0642	0.1178	0.2577	0.5545	0.3372	0.1164	0.2099	0.2278
PKE(m/s2)	0.161	0.0105	0.0527	0.0259	0.1635	0.0114	0.4143	0.0257	0.1914	0.2426	0.1257
Total Deviation		**3.4595**	**5.4824**	**0.5211**	**0.7646**	**2.1188**	**1.9489**	**2.9555**	**1.1783**	**2.9165**	**2.2015**
SSD		**0.012**	**0.029**	**0.03**	**0.033**	**0.027**	**0.013**	**0.071**	**0.031**	**0.029**	**0.022**

Appendix 8: Candidate cycles for traffic engineering purpose

	Population	Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
Average Speed(kmph)	19.977	19.809	0.008	19.882	0.005	19.913	0.003	19.987	0.000	20.003	0.001
Average Running Speed(kmph)	25.319	25.116	0.008	25.170	0.006	25.156	0.006	25.279	0.002	25.339	0.001
Average Acceleration(kmh-1s-1)	3.288	3.250	0.012	3.242	0.014	3.218	0.021	3.252	0.011	3.255	0.01
Average Deceleration(kmh-1s-1)	1.955	1.961	0.003	1.971	0.008	1.985	0.015	1.973	0.009	1.976	0.011
Acceleration Proportion	0.365	0.366	0.002	0.365	0.001	0.369	0.010	0.368	0.008	0.366	0.002
Deceleration Proportion	0.294	0.293	0.002	0.294	0.000	0.292	0.005	0.292	0.005	0.293	0.002
Idling Proportion	0.211	0.211	0.002	0.210	0.004	0.208	0.012	0.209	0.008	0.211	0.002
Cruising Proportion	0.130	0.129	0.004	0.130	0.003	0.131	0.004	0.130	0.003	0.130	0.002
Average Micro Trip Duration	711.849	728.448	0.023	732.552	0.029	735.414	0.033	726.414	0.020	730.414	0.026
Total Deviation			0.034		0.029		0.047		0.026		0.014
SSD			0.028		0.022		0.024		0.043		0.033