Proceedings of the 9th APTE Conference
6th - 8th August 2014, Mount Lavinia Hotel, Sri Lanka

# NEW METHODOLOGY FOR DEVELOPING DRIIVNG CYCLE(S) FOR SRI LANKA; CASE STUDY, COLOMBO, SRI LANKA.

| Uditha Galgamuwa | Loshaka Perera | Saman Bandara |
|---|---|---|
| Graduate Research Student, Transportation Engineering Division Department of Civil Engineering, University of Moratuwa Email: nandun8781@gmail.com | Senior Lecturer, Transportation Engineering Division, Department of Civil Engineering, University of Moratuwa Email: perera.loshaka@gmail.com | Professor, Transportation Engineering Division, Department of Civil Engineering, University of Moratuwa Email: bandaras@sltnet.lk |

**ABSTRACT**

Even though driving cycles have been adopted around the world in different type of applications, the data needed for each steps is costly and time consuming. Majority of the Developing countries do not have systematic data bases for traffic related information such as origin-destinations, vehicle kilometers, average annual daily traffic etc. for majority of road links. Meager amount of available data is not sufficient to develop a driving cycle. Even though the data is collected, significant effort has to be made to construct a driving cycle that closely matches to the population data set. This paper gives simplified methodology for developing driving cycles using different approaches for route selection, data collection and cycle construction. For the route selection the available methods have been combined together and modified to suit for developing countries where no details traffic flow information will be available. Also a method was adopted for data collection by dividing selected routes in to links and grouped them according to daily traffic to optimize the cost for data collection. Road links were divided using physical junctions on the road and routes were selected using traffic generators and attracters combined with Origin Destination data. Also methodology was developed for synthesize data population using collected data from road links. Another issue for cycle construction is to construct a cycle which is close to population parameters. Using existing methods many cycles have to be constructed until the acceptable cycles is generated. New methodology has been adopted to develop driving cycle to match the population parameters and then to select data for driving cycle using Markov chain. As a case study Colombo, Sri Lanka has selected to apply the new approach of driving cycle construction for developing countries.

**Key words:** Driving Cycle, Emission, cycle construction

## 1. INTRODUCTION

World is moving towards sustainable transportation systems during the past few decades. Fuel efficiency and transportation emission are the main driving forces. Many methods have been adopted for developing emission inventories and estimating fuel economy and those can be divided in to two groups namely travel based models and fuel based models (Xiao, 2012). Fuel based methods are empirical methods which use results to model and predict the behavior (top to bottom approach) and travel based models use the data and develop a model to predict the behavior after analyzing the data (bottom up approach).

One of the widely used methods to model and predict the traffic behavior hence predicts fuel consumption and emission inventories is driving cycle. It can be categorized under travel based methods. Many countries have developed different methods for developing driving cycles and the comparison of existing driving cycles have been done previously and methods suitable for Sri Lankan conditions have been identified(Galgamuwa, 2014). Colombo, Sri Lanka was selected as a case study to develop a driving cycle where a basic driving cycle for a selected route has been developed

(Gamalath, 2012). Due to lack of systematic traffic data, a new methodology was adopted for route selection and data collection hence the cycle construction methodology.

## 2. ROUTE SELECTION

Route selection is one of the major steps in developing driving cycles. The routes selected have to represent the traffic behavior of the area where the driving cycle is to be developed and if not the results obtain from the driving cycle will be deviate from its actual situation. When selecting routes consideration must be given to traffic flow, the other conditions with respect to traffic (spatial and temporal), land use, road type, topography, population density etc.( Tong and Hung 2010: Barrios, 2012).

A major problem in many developing countries is lack of systematic traffic related information. Hence it is difficult to use an advanced method such as Australia (Australian Composite Urban Emission Driving Cycle), Hong Kong driving cycle etc. Therefore a new method was adopted for Colombo after analyzing available traffic flow data. Traffic flow can be divided in to two categories namely intercity and intra city. Therefore the routes have to be selected for those two types separately.

### 2.1. Route Selection for Intercity Trips

Route selection for intercity trips were done using origin destination data (OD) and daily traffic flow data at 10 main entry points to city of Colombo. For the OD survey the locations were selected such that to cover the major corridors where the traffic fleet enters the Colombo. Selected ten locations are shown in figure 1 and names of those locations are given below

Gamsabha Junction(Aththidiya road)
Piliyandala
Mattakkuliya (Canal Road)
Grandpass (Negambo Road)
Rajagiriya (Sri Jayawardanapura Mawatha)
Kohuwela (Horana Road)
High Level
Dehiwala (Galle Road)
Kelanithissa(Kandy road)
Orugodawatta (Awissawella Road)

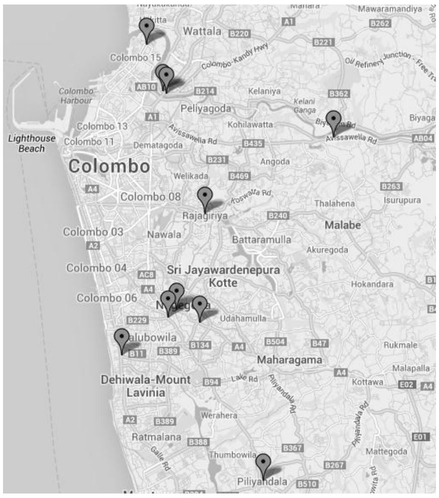


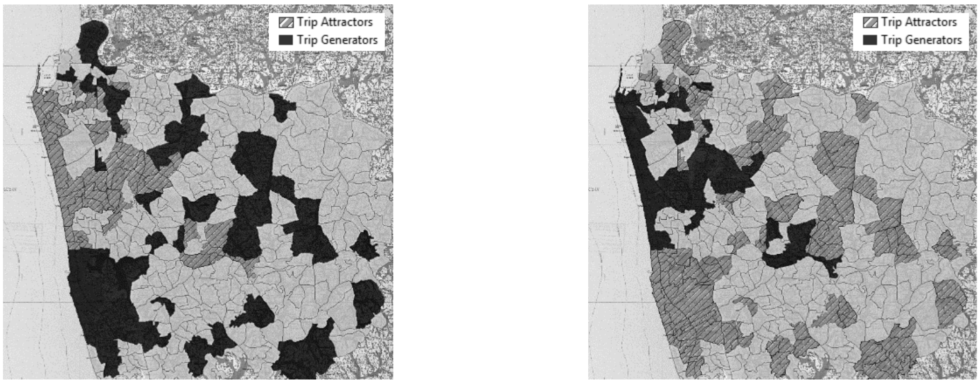

Figure 1: OD locations for Colombo

Data from OD surveys was analyzed. 57 routes were selected by considering the frequency (routes which accommodate more than 70% of the vehicle fleet which enter Colombo from respective corridor

### 2.2. Route Selection for Intracity Trips

Even though the routes were selected for intercity trips based on OD data, it is difficult, costly and time consuming to carry out OD for intra city trips due to economical constrains. Hence the routes were selected considering traffic generators and traffic attractors.

Using population data and land use pattern the trip generators and trip attractors have been identified according to the GN (Gramasewa Niladari) divisions (Smallest administrative areas for the population and household data is available) . Also according to the time of the day the generators and attractors changes. In Colombo, in the morning the residential areas generate traffic and commercial areas and schools attract the traffic. But in the evening the generators become attractors and attractors become generators. 52 trip attractors (Commercial and schools) and 116 trip generators have been identified in GND wise. Then the route network is laid on the map and routes were identified which connect trip generators and trip attractors using ArcGIS 10.2 software. 72 different routes were identified for intra city tips.




In the morning In the evening

Figure 1: Trip generator and Trip attractors in different periods of the day

2.3. Routes Selected For Data Collection

After identified the routes for intercity (57 routes by analyzing OD data) and intra city trips (72 routes using Trip generators and attractors) the routes were laid on a same map. Then the superimposed road layer is divided in to route links using physical junctions. A Total of 121 route links were identified to use to collect speed time data in Colombo region using selected data collection method to synthesize the data population.

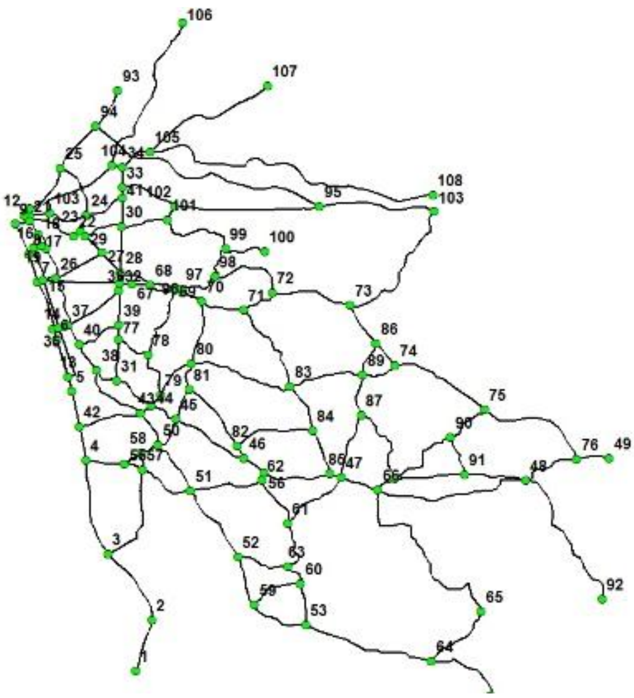


Figure 2: Selected route links for data collection

## 3. DATA COLLECTION

Data collection becomes 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. Mainly there are two types of data collection methods namely, chase car method and on board measurement method (Tong et al., 2000). It is possible to combine above two methods to a one known as Hybrid method (Tong and Hung, 2010)

Considering the traffic behavior of the Colombo city and resource availability, on board measurement method was selected as a data collection method. Number of data samples required for each link was identified proportionate to the daily traffic estimates. The required numbers of samples were further divided in to time period of the day using hourly traffic volumes in corresponding routes. For that, the day was divided in to seven segments namely morning off peak, morning peak, inter peak 1, school peak, inter peak 2, evening peak and evening off peak. Then the routes were assigned in to five groups according to daily traffic by giving number 1 to the lowest daily traffic volume and number 5 to the highest daily traffic volume. Number of segments to be divided is decided by researcher from the knowledge of the area of concern. Simply it is to identify and grouped road links which have similar traffic characteristics and behavior. Further consideration was given the variation of traffic flow within the day. Because the time of the day affect the traffic flow in given road hence affect the speed time data collected in that road. Therefore seven segments defined used to select number of samples and selected samples are shown in table 1 it is given for minimum sample size which is one. (At least there should be one sample from each segment and the segment which has minimum traffic flow has number one as circled in the table 1)

Table 1: Sample distribution within the road groups and time of the day (for minimum sample size)

| | Morning Off Peak | Morning Peak | Inter Peak1 | School Peak | Inter Peak2 | Evening Peak | Night Off Peak | Total |
|---|---|---|---|---|---|---|---|---|
| Road Group 1 | 2 | 3 | 3 | 2 | 1 | 3 | 2 | 16 |
| Road Group 2 | 1 | 4 | 4 | 4 | 3 | 4 | 3 | 23 |
| Road Group 3 | 5 | 7 | 4 | 4 | 4 | 8 | 3 | 35 |
| Road Group 4 | 5 | 10 | 7 | 6 | 4 | 7 | 4 | 43 |
| Road Group 5 | 10 | 15 | 8 | 11 | 15 | 15 | 12 | 86 |

## 4. CYCLE CONSTRUCTION

Method of cycle construction varies with the purpose of the driving cycle whether it is for estimation of emission inventories or estimation of fuel consumption or traffic engineering purposes. Each cycle construction method has its unique features to represent its' envisioned purpose (Galgamuwa, 2014). Model cycle construction is selected for this study as it can capture the each and every state of driving since it is used Markov model for segment and select data for developing driving cycle. In Modal cycle construction actual driving patterns are divided in to acceleration, deceleration, cruising and idling events. To construct the Driving Cycle Markov Chain theory is used hence assume that the likelihood of particular modal event depends only upon the pervious modal event (Lin and Niemeier, 2003). There are four basic steps for constructing driving cycle using Modal cycle construction method. (Dia et al 2008 cited Lin and Niemeier 2002)

1. Using maximum likelihood estimation on road data is partitioned into snippets of various duration based on acceleration.
2. Using maximum likelihood estimation snippets are assigned into modal bins considering variables such as 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

The method available considers the probability of state changes and then select data according to highest probability of state change from initial state. And then Speed acceleration frequency distribution is considered and select the best cycle which matches the population parameters. The available method has been modified by combining two matrices of probability of state changes and probability of state changes. Then it is not necessary to consider SAFD when selecting each and every data set for the driving cycle. The modified method is used to develop driving cycle for Colombo, Sri Lanka. Methodology for cycle construction is as below.

### 4.1. Defining the States Used in Transition Probability Matrix

According to the previous study done, states have been defined using speeds and accelerations and assigned them in to different modal bins. (Shi, 2011)

Table 2: Definition for the states used in transition probability matrix

| | $a \leq -0.8$ | $-0.8 < a \leq -0.1$ | $-0.1 < a \leq 0.1$ | $0.1 < a \leq 0.8$ | $a > 0.8$ |
|---|---|---|---|---|---|
| $0 < v_m \leq 25$ | 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

v- Speed (km/h)

a- Acceleration ($m/s^2$)

### 4.2. Preparing the Transition Probability Matrix for State Changes

Then a transition probability matrix is prepared which represent the probability of mode changes from one state to another based on the Markov chain model. The sample of the matrix is shown in table 3.

Table 3: 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 | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | | |

### 4.3. Calculating the Proportions of States

Then calculate the time proportion of each twenty one states using population data set. Proportions calculated for state 0,1,2,3 …. n are defined as $p_0,\ p_1,\ p_2,\ p_{3\ldots\ldots}\ p_n$ respectively.

### 4.4. Calculating the Time for Driving Cycle from each Mode

Calculate the time in each state with in the driving cycle (time allocated for each state with in 1200s duration of driving cycle). The duration of the driving cycle is kept as 1200s to optimize the running cost of developed cycle on chassis dynamometer. Sample calculation is given in table 4.

In table 4, Xi is the time used for diving cycle from each mode. At the beginning $X_i$ 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 1.

The probability for i$^{th}$ state

$$P_i = \frac{[(1200 \times pi) - Xi]}{1200 - \sum_{i=0}^{i=20} Xi} \qquad (1)$$

*When* $\sum_{i=0}^{i=20} Xi = 1200$ *the cycle stops.*

Table 4: 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 | $(1200 \times p_2) - X_2$ | $P_2$ |
| | | |
| 19 | $(1200 \times p_{19}) - X_{19}$ | $P_{19}$ |
| 20 | $(1200 \times p_{20}) - X_{20}$ | $P_{20}$ |

4.5. Developing New Transition Probability Matrix

After calculating the new probabilities of each driving mode (table 4) and prepare a transition probability matrix for new probabilities of state changes by multiplying probability of state changes column by probability of corresponding probability of state changes. Example for calculating new probabilities of state changes are shown in table 5

Table 5: 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 $j^{th}$ state

Note-

When one mode is selected, the time allocated for the respective state is reduced hence the probabilities will decreased and it allow the states which haven't been selected previously or haven't been selected frequently to increase their probabilities. Then those states which have higher probability in new transition probability matrix for state changes will have higher chance of get selected for the driving cycle.

4.6. Data Selection Criteria

Initially a data set from state 0 is selected. Then the state which has higher probability from state 0 is selected according to the new transition probability matrix (Higher probability state from state 0 is in state 0 row). Then the new transition probability matrix is calculated according to new probabilities for each 21 states. Again the higher probability state was selected from current state (the highest probability of current state row in new transition probability matrix).Likewise the data is selected for the driving cycle until the time requirement is fulfill. (For each selection the new probabilities are calculated and update the new transition probability matrix)

## 5. CYCLE ASSESSMENT

Many parameters have been identified for cycle assessment in the literature according to purpose of the cycle construction. Out of those parameters ten parameters have been identified which will assess the emission related driving cycles.

1. Average speed of the entire driving cycle
2. Average running speed
3. Average acceleration
4. Average deceleration
5. Time proportions of driving modes for idling
6. Time proportions of driving modes for acceleration
7. Time proportions of driving modes for cruising
8. Time proportions of driving modes for deceleration
9. Root mean square acceleration (arms)
10. Positive kinetic energy (PKE)

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 behavior of selected road or region which has a lower Performance value where the definition of the Performance Value (PV) is given below.

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

If developed candidate cycles have similar or approximately close PV values then the Speed Acceleration Frequency Distribution (SAFD) is considered. Then the Smallest Sum Square Difference (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.

## 6. DATA VALIDATION

Data validation is important to make sure that the data collected are true representatives of actual travel pattern in the area of concern. The following method was adopted for data validation.

First calculate the 10 parameters used for cycle assessment for the data population used for constructing candidate cycles. Then one continuous data set is collected using roads which covers major and minor roads and according to the road groups. Same parameters calculated for the population will be calculated for the collected data set using major and minor roads. Then compare with the population parameters. If the parameters calculated using dataset lies within the allowable range (15% upper limit and 5% lower limit) (Kamble, 2009) compared to the population parameters the population data set is considered as representative data set.

## 7. RECOMMENDATIONS

Since it consider speed acceleration probability distribution of the population when selecting data for candidate cycle the cycle represent the actual driving pattern in the area of concern. But if the driving behavior is uniform (if the state changes do not occur frequently) the cycle will deviate from population. Therefore this method is suitable for the areas where the uneven driving pattern occurs. If the method is used such areas where there are not much variation of speeds length of the driving cycle should be increase to minimize the error or states have to be define as accordingly.

The accuracy of the driving cycle depends on the data collected. It is advisable to use all routes selected and collect data proportionate to its daily traffic. If the time and the budget is limited collect data from the groups as given in the methodology but there the data validation should be done.

Parameters have to be selected carefully to assess the developed driving cycle because the predominant parameters are changed due to purpose of the driving cycle. The driving cycle constructed using this method might seem unrealistic than micro trip method since the data is selected using probabilistic method.(in micro trip method acceleration, cruising, deceleration and idling considers as one data set where in Modal cycle construction method divide those micro trip in to further states based on acceleration and average speeds). But it is proven that the new approach gives more accurate results than micro trip method (Using sample data set collected). Sometimes it might be difficult to run on chassis dynamometer (Old chassis dynamometer which cannot capture frequent fluctuations). Therefore results from this method must be analyzed carefully and smooth the cycle using statistical method such as time series analysis without deviating the parameters with population parameters.

## 8. REFERENCES

Barrios, C. C., Dominguez-Saez, A., Rubio, J. R., & Pujadas, M. (2012). Factors influencing the number distribution and size of the particles emitted from a modern diesel vehicle in real urban traffic. *Atmospheric Environment*, 16-25.

Dia, Z., Eisinger, D., & Niemeier, D. (2008). *DRIVING CYCLES: A NEW CYCLE-BUILDING METHODTHAT BETTER REPRESENTS REAL-WORLD EMISSIONS.* California: Davis.

Gamalath, I. M., Galgamuwa, U. N., Fernando, C. M., Perera, L., & Bandara, J. J. (2012). Methodology to Develop a Driving Cycle for a Given Mode and Traffic Corridor; Case Study for Galle Road,Colombo, Sri Lanka. *Proceedings of the Civil Engineering Research for Industry Symposium, University of Moratuwa*, 45-50.

Galgamuwa, U. N.(2014). Developing Driving Cycles for Sri Lanka (unpublished master's thesis). University of Moratuwa, Moratuwa, Sri Lanka.

Hung , W. T., & Tong, H. Y. (2010). A Framework for Developing Driving Cycles with On Road Driving Data. *Transport Review*, 589-615.

Kamble, S. H., Mathew, T. V., & Sharma, G. K. (2009). Development of real-world driving cycle: Case study of Pune, India. *Transportation Research Part D*, 132-140.

Lin, J., & Niemeier, D. A. (2003). Regional driving characteristics, regional driving cycles. *Transportation Research Part D*, 361-381.

Shi, Q., Zheng, Y. B., Wang, R. S., & Li, Y. W. (2011). The study of a new method of driving cycles construction. *Procedia Engineering*, 79-87.

Tong, H. Y., Hung, W. T., & Cheung, C. S. (2000). On-Road Motor Vehicle Emissions and Fuel Consumption in Urban Driving Conditions. *Air and Waste Management Association*, 543-554.

Xiao, Z., Dui-Jia, Z., & Jun-MIn, S. (2012). A Synthesis of Methodologies and Practices for Developing Driving Cycles. *Energy Procedia*, 1863-1873.

## Acknowledgements

Authors are thankful to Dr. Thusitha Sugathapala for the guidance and motivation given and further thank goes to Sustainable Energy Authority for the resources provided for the success of this research