J. Viet. Env. **2016**, Vol. 8, No. 4, pp. 247-251
DOI: 10.13141/jve.vol8.no4.pp247-251

JOURNAL of VIETNAMESE ENVIRONMENT

Impact of the driving cycle on exhaust emissions of buses in Hanoi

Tác động của chu trình lái tới sự phát thải khí xả của xe buýt tại Hà Nội

Research article

Nguyen, Thi Yen Lien[1,2*]; Nghiem, Trung Dung[2]; Cao, Minh Quý[1]

[1]*School of Environmental Science and Technology, Hanoi University of Science and Technology;* [2]*Faculty of Transport Safety and Environment, Hanoi University of Transport and Communication, Vietnam*

The impact of driving cycle on exhaust emissions of buses in Hanoi was presented in this article. A typical driving cycle of buses in Hanoi was developed based on the real-world driving data, and it also was assessed that has a good conformity with the real-world driving data. The typical driving cycle and European Transient Cycle part 1 (ETC-part1) were used to estimate vehicle emission according to different driving cycles. The obtained results showed that emissions level of CO, VOC, PM, CO_2 and NO_x of the buses were very different between two driving cycles, especially CO_2 and NO_x. This paper, therefore, reconfirms the necessity of the development of the typical driving cycle before conducting the emission inventory for mobile sources.

Tóm tắt: Tác động của chu trình lái tới sự phát thải của xe buýt tại Hà Nội đã được trình bày trong bài báo này. Một chu trình lái đặc trưng của xe buýt Hà Nội đã được xây dựng dựa trên dữ liệu hoạt động ngoài thực tế của phương tiện, và chu trình lái này cũng đã được đánh giá có sự phù hợp rất cao với dữ liệu lái ngoài thực tế. Chu trình lái đặc trưng và chu trình thử ETC-part1 được sử dụng để đánh giá phát thải của phương tiện theo các chu trình lái khác nhau. Các kết quả đạt được cho thấy mức độ phát thải CO, VOC, PM, CO_2 *và* NO_x *của xe buýt rất khác nhau giữa hai chu trình lái, đặc biệt là* CO_2 *và* NO_x*. Do đó, bài báo khẳng định sự cần thiết phải xây dựng chu trình lái đặc trưng trước khi thực hiện kiểm kê phát thải đối với nguồn động.*

Keywords: driving cycle, driving feature, bus, emission, real-world driving data

1. Introduction

Motor vehicles are one of the main sources of air pollutants in big cities, especially in developing countries. The emission of a vehicle is dependent on several factors including the type and age of the vehicle, air pollution control technologies used, the type and quality of fuel, ambient air conditions and its operating conditions (cold-start, steady-state cruise, acceleration, and deceleration, idle), etc.

Emission factor (EF) is a useful tool to evaluate emissions of air pollutants, and it is being widely used in the emissions inventory in many countries. For motor vehicles, the widely used method to determine EF is vehicle emission measurement under controlled conditions in the laboratory (engine and chassis dynamometer studies) with the use of a driving cycle which is built based on real-world activity data (Franco *et al.*, 2013).

The driving cycle represents the relationship between the instantaneous speed and time of an on-road vehicle in certain conditions, so the driving cycle fully reflect real traffic conditions. Therefore, the driving cycle impacts strongly on the vehicle emission. In this study, we used a GPS device with the update rate of 1 Hz to collect the real–world driving data of the five bus routes in Hanoi, namely No. 9, 18, 25, 32 and 33, on weekdays and weekends. These GPS data were processed to improve their quality before using them to develop the candidate driving cycle for buses in Hanoi. The IVE model was used to estimate vehicle emission based on different driving cycles including candidate driving cycle and ETC-part1.

* Corresponding author
E-mail: nylien@utc.edu.vn

http://dx.doi.org/10.13141/JVE
ISSN 2193-6471

2. Methodology

The methodology of this study is presented on Figure 1.

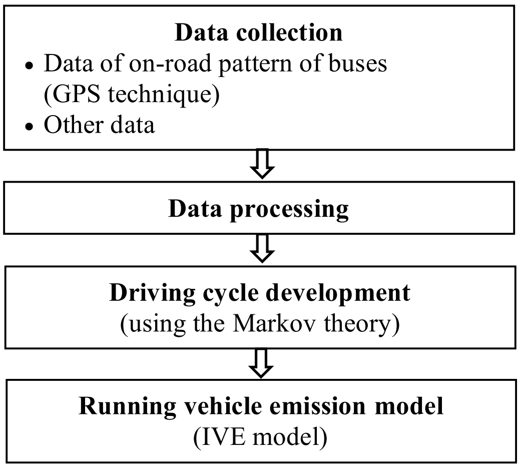

Figure 1. Framework of methodology

2.1. Data collection

Real-world driving characteristics can be fully determined if we have sufficient data recording the velocity of vehicle over survey time. In this study, we used Global Positioning System (GPS) technology to collect the real-world driving data of five bus routes in Hanoi (No.09, 18, 25, 32 and 33). The GPS technology have proven useful tools for gathering real-world driving data because vehicle speed-time and position data can be captured continuously (Niemeier *et al.*, 1999; Tong and W.T.Hung, 2010)). A Garmin etrex vista HCx equipment with the update rate of 1 Hz was used for this purpose.

Five bus routes shown in Table 1 were selected for this study. On each route, a bus was selected. These on-road driving data were recorded on this bus, continuously from the starting point at around 6 am to the finishing point at around 8 pm. The data were recorded with time step of one second to avoid losing information. These data were collected from July to October, 2015.

Table 1. The information of five bus routes used in this study

Route	Type of route	Starting point	Finishing point
09	Closed	Hoan Kiem Lake	Hoan Kiem Lake
18	Closed	National Economics University	National Economics University
32	Radial	Giap Bat Coach Station	Nhon transfer station
25	Ordinary	Nam Thang Long Car Parking	Giap Bat Coach Station
33	Ordinary	My Dinh Coach Station	Xuan Dinh

2.2. Data processing

The unique operating behavior and errors inherently associated with GPS data loggers must processed before using them to driving development. The ideal filtration method for improving the quality of raw GPS data is one that minimizes the effects of GPS data logging errors such as sudden signal loss, data spiking, signal white noise, and zero speed drift while maintaining the integrity of the raw source data (Duran and Earleywine, 2012). In this study, the proposed filtration process for improving the quality collected GPS data is presented in Figure 2.

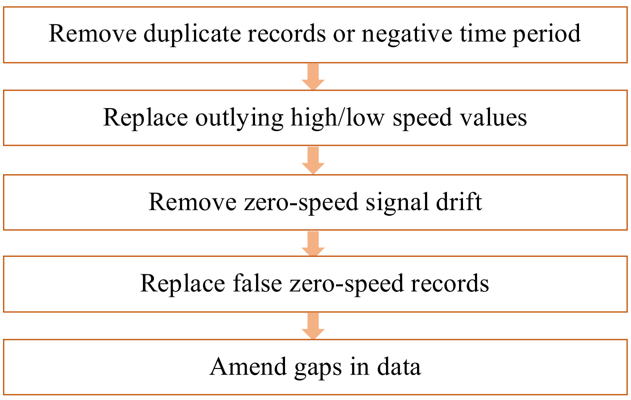

Figure 2. Flowchart of GPS data filter

Remove duplicate records or negative time period

As an initial step in the filtration process, it is necessary to remove any data points with duplicate time values and data points that have negative or zero differential time values. To remove these points, the filter first calculates the differential time values for each of the data points in the source set and then removes any with differential time values less than or equal to zero (Duran and Earleywine, 2012).

Replace outlying high/low speed values

In this step, any erroneous data points, such as high-speed data spikes and negative speed signal dropouts, that are present in the data set are removed and replaced with interpolated data (Duran and Earleywine, 2012). The limit speed value is determined and each speed value in the sample set compared to the speed limits. If the data point is found to lie outside the chosen limits, the filter replaces the source sample data point with speed value derived from a spline interpolation from neighboring data.

Remove zero-speed signal drift

During extended-duration idle events, GPS data loggers will often record a very small speed value (0.1 or 0.2 mph) due to GPS satellite signal reacquisition that occurs when a vehicle is stopped. This speed values are called "zero speed drift" (Duran and Earleywine, 2012). To remove "zero speed drift" we determine microtrips which consist only of speed values equal zero or smaller than 0.2mph and all speed values differ zero are replaced by zero.

Replace false zero-speed records

If a given speed record value is zero and the neighboring points on each side are both nonzero, the zero-speed point is replaced with a speed value which is derived from a linear interpolation from neighboring data.

Amend gaps in data

In this step, the filtration algorithm attempts to correct for gaps in the coupled speed-time GPS signal caused by urban canyon effects and sudden signal loss (Duran and Earleywine, 2012). The filter detect time gaps which greater than one second and add some "new" speed data that generate based on interpolated cubic spline curve is determined from the entire remaining data set.

A Matlab code was built to perform these filtration steps.

2.3. Driving cycle development

In this study, the Markov chain theory was used to develop a driving cycle. In order to do so, firstly, the speed-acceleration (VA) probability must be calculated. Therefore, the two-dimension distribution map of velocity and acceleration is divided into grids to define the states. Each grid stands for one kind of state. All one-step state probabilities can be arranged in a matrix which is called the transition probability matrix (TPM), where each element contains the probabilities for every other state to be the next in the chain.

The size of the matrix is determined by the maximum velocity and the absolute maximum acceleration, combined with the resolutions for velocity and acceleration. The numbers of rows (n_r) and columns (n_c) are calculated as follows (Nyberg and Frisk, 2013):

$$n_r = 2.\frac{|a|_{max}}{a_{res}} + 1 \quad (1)$$

$$n_c = 2.\frac{v_{max}}{v_{res}} + 1 \quad (2)$$

When a TPM has been created, it is possible to start generating a driving cycle with start point is the idle state (zero velocity and acceleration).

The candidate driving cycle will be assessed the conformity with the real-world driving data by analysing the difference between Speed Acceleration Frequency Distribution (SAFD) of the candidate driving cycle and the real-world driving data. In order to calculate SAFD, the speed and acceleration fields are divided into equal cells (being called bins) and the probability for each cell is determined. $SAFD_{diff}$ is the percentage difference between the SAFD of all bins in the real-world driving data and the developed driving cycle as defined by Equation 3. The smaller $SAFD_{diff}$ is, the higher the commonality between the two cycles is (Ashtari *et al.*, 2014; Brady and O.Mahony, 2013).

$$SAFD_{diff} = \frac{\sum_i (SAFD_{cycle}(i) - SAFD_{data}(i))^2}{\sum_i (SAFD_{data}(i))^2} \quad (3)$$

Where, i is the i^{th}bin in the SAFD, $SAFD_{cycle}$ is the SAFD of the developed driving cycle, and $SAFD_{data}$ is the SAFD the collected data.

2.4. Emission calculation

IVE (International Vehicle Emissions) model was used to simulate the vehicle emission based on the candidate driving cycle for bus in Hanoi and European Transient Cycle part 1 (ETC-part1). IVE model was developed by the US Environmental Protection Agency (US. EPA). It was designed specifically to be able to meet flexible needs of developing countries in an effort to determine gas emissions from mobile sources.

The speed-time data in the candidate driving cycle and ETC cycle were used to determine two very important parameters in IVE model:

+ **VSP** (Vehicle Specific Power) is defined as a power per unit mass to overcome road grade, rolling and aerodynamic resistance, and inertial acceleration:

$$VSP = v\times[1.1\times a+9.81\arctan(\sin(grade))+0.132] + 0.000302\times v^3 (kW/ton) \quad (4)$$

Where: a – acceleration (m^2/s); v – speed (m/s); grade – road grade (radian)

+ **ES** (Engine stress**)** is the parameter correlating the vehicle power load experienced over the past 20 seconds of operation, from t = -5 to -25 sec, and the implemented RPM (Revolution Per Minute) of the engine. The Engine stress is calculated using Equation 5 (International Sustainable Systems Research Center ISSRC, 2008):

$$\textbf{ES} \text{ (unitless)} = \text{RPMIndex} + (0.08 \text{ ton/kW})\times \text{PreaveragePower} \quad (5)$$

Here:
PreaveragePower = Average ($VSP_{t=-5 \text{ to } -25sec}$) (kW/ton)

RPMIndex = $Speed_{t=0}$/SpeedDivider (unitless).

3. Results and discussions

3.1. Data collection and processing

The real-world driving data collected on five buses in Hanoi consist of 97 trips. All trips were processed for improving the quality of raw GPS data. The results of data processing are shown in Table 2.

Table 2. The percentage of errors in raw GPS data

Errors	Proportion (%)
Negative/Duplicate	0
Outlying high/low speed	0.002
Zero drift speed	0.280
false zero-speed	0.412
Amend gaps	4.048

3.2. Candidate driving cycle for the bus in Hanoi

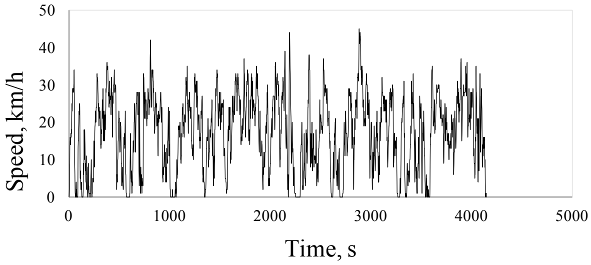

Figure 3. Candidate driving cycle for Hanoi bus

The input data consist of 97 trips, where each trip is the data of real-world vehicle instantaneous speeds which were recorded from the starting point to finishing point of each bus route. With v_{res} = 1km/h and a_{res} = 0.2m/s^2, the size of TPM which was determined based on the input data is 73 rows and 57 columns.

The candidate driving cycle for the bus in Hanoi was developed based on the Markov theory and is shown on Figure 3.

For the recorded driving data of the bus route No. 9 and the developed driving cycle, the $SAFD_{diff}$ is 11.2%. This result is smaller (meaning better) than other studies which used other methods (microtrip or trip snippets) for designing the driving cycle. For example, the test cycle FTP72 has $SAFD_{diff}$ = 17.7%, the test cycle FTP75 has $SAFD_{diff}$ = 30.4% (Ashtari *et al.*, 2014).

Some typical parameters of the candidate driving cycle for Hanoi bus in comparison with ETC-part1 are determined and presented in Table 3. It can be seen from Table 3 that typical parameters of two driving cycles are huge different. The proportion of time standing of bus system in Hanoi is very higher than those of ETC-part1, but the average speed of Hanoi but is smaller. These results, therefore, are reasonable and reflect the real conditions of the transport system in Hanoi, where the intersections of the roads are mainly in the same level and traffic jams are frequently happened.

Table 3. Some typical parameters of the candidate driving cycle of bus system in Hanoi

Parameter	Candidate cycle	ETC-part1
Duration (s)	4104	600
Distance (km)	19.7	3.87
Average speed (trip) (km/h)	17.28	23.3
Average driving speed (km/h)	18.25	23.25
Max speed (km/h)	41.00	90.8
Standard deviation of speed (km/h)	10.19	13.27
% of time accelerating (%)	34.50	40.83
% of time decelerating (%)	32.38	32.00
% of time standing (%)	5.31	0.00
Average positive acceleration (m/s^2)	0.48	0.273
Average negative acceleration (m/s^2)	-0.51	-0.313
Positive kinetic energy (m/s^2)	0.32	3.532

3.3 Emission factors

In order to estimate the impact of driving cycles to vehicle emissions, the IVE model was applied to simulate vehicle emissions in different driving cycle, that is the candidate driving cycle and ETC-part1, but with the same vehicle type, fuel type and meteorological conditions. The emission factor in the running mode is used in this study. Results obtained are shown in Table 4. It can be seen from Figure 4 that the emission factors consisting of all pollutants of a bus simulated according to the candidate driving cycles is always higher than ETC-part1. This results are consistent with results showed in Table 3 because the candidate driving cycle has characteristics which can increase vehicle emission, for example: the average speed and time standing are higher than ETC-part1. In short, vehicle emission is depended strongly on driving cycle. This results, therefore, reconfirm the necessity of designing the typical driving cycle before conducting the emission inventory of mobile sources.

Table 4. Emission factors according to different driving cycles

Pollutants	Candidate cycle (g/km)	ETC-part1 (g/km)
CO	2.70	1.98
VOC	0.96	0.68
NO_x (as N)	13.89	10.10
SO_x	0.11	0.08
PM	2.18	1.59
CO_2	1062.33	805.33

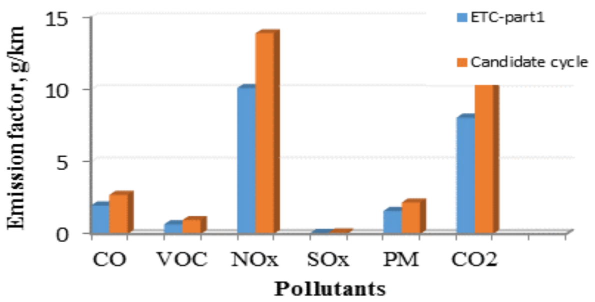

Figure 4. Pollutants emission as a function of each driving cycle ($EF_{CO2}x10^{-2}$)

4. Conclusions

The on-road driving data of five bus routes in Hanoi were collected and processed. These processed data were used to develop the candidate driving cycle for bus system in Hanoi. The driving cycle developed in this study is fit in the real-world driving data ($SAFD_{diff}$= 11.3%) but its driving characteristics are very different from that of ETC-part1. The speed-time data in the candidate driving cycle and ETC-part1 were used to determinate bus emission factors by IVE model. The obtained results show that vehicle pollutants emission factor as a function of driving cycle. Therefore, the emission factors of motor vehicles must be determined based on the driving characteristics of local traffic conditions. In other words, the application of the test cycles from other countries for the determination of the emissions in Vietnam may produce erroneous results. This paper, therefore, reconfirms the necessity of the development of the typical driving cycle before conducting the emission inventory of mobile sources.

5. References

[1] Ashtari, A., Bibeau, E., & Shahidinejad, S. (2014). Using Large Driving Record Samples and a Stochastic Approach for Real-World Driving Cycle Construction: Winnipeg Driving Cycle *Transportation Science, 48*(2), 170 - 183.

[2] Brady, J., & O. Mahony, M. (2013). The development of a driving cycle for the greater Dublin area using a large database of driving data with a stochastic and statistical methodology. *Proceedings of the ITRN2013*.

[3] Duran, A., & Earleywine, M. (2012). GPS Data Filtration Method for Drive Cycle Analysis Applications. SEA International.

[4] Franco, V., Kousoulidou, M., Muntean, M., Ntziachristos, L., Hausberger, S., & Dilara, P. (2013). Road vehicle emission factors development: A review. *Atmospheric Environment, 70*, 84-97.

[5] International Sustainable Systems Research Center ISSRC. (2008). IVE Model Users Manual Version 2.0 from www.issrc.org/ive.

[6] Niemeier, D. A., Limanond, T., & Morey, J. E. (1999). Data collection for driving cycle development: evaluation of data collection protocols. Department of Civil and Environmental Engineering, Institute of Transportation Studies, University of California, Davis.

[7] Nyberg, P., & Frisk, E. (2013). *Driving cycle generation using statistical analysis and Markov chain*. Department of Electrical Engineering, Likopings University, Sweden.

[8] Tong, H. Y., & W.T.Hung. (2010). A Framework for Developing Driving Cycles with On-Road Driving Data. *Transport Reviews: A Transnational Transdisciplinary Journal, 30*(5), 589-615.