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Development of a driving cycle for intra-city buses in Chennai, India

K.S. Nesamani [a,*], K.P. Subramanian [b,1]

[a] Institute of Transportation Studies, 4000 Anteater Instruction and Research Bldg (AIRB), University of California, Irvine, CA 92697, USA
[b] Urban Systems Engineering, Anna University, Chennai 600 035, India

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ABSTRACT

In India the emissions rate and fuel consumption of intra-city buses are estimated using the European driving cycles, which don't represent Indian driving conditions and in-use operation of vehicles. This leads to underestimation or overestimation of emissions and fuel consumption. In this context, this paper offers some insight into the driving characteristics of intra-city buses using a Global Positioning System. The study has revealed that irrespective of road type and time of travel, a higher percentage of time is spent in idle mode. This is primarily due to alighting and boarding of passengers at regular intervals and fixed delays caused by traffic lights. More than 90 percent of trips have an average speed of less than 30 km h^{-1}. This study has also developed an intra-city bus driving cycle for Chennai and compared it with some well-known international driving cycles. It has revealed that Chennai has unique driving characteristics and, therefore, it may not be appropriate to adopt a driving cycle of another country or city.

1. Introduction

Buses are environmentally friendly in terms of per capita energy consumption and emission. They are relatively inexpensive and provide a low level of service and comfort. States government-owned buses provide public road transportation services in India. The modal share of buses ranges from 5 to 40 percent in urban cities (WSA, 2008). The average age of buses in India ranges between 3.25 years and 10.33 years (Ramasaamy, 2006). Average trip lengths in cities have increased significantly due to urban sprawl. Consequently, this has increased the number of motor vehicles about 183 times over the past five decades whereas the number of buses increased only by 17 times during the same period (Nesamani, 2010). Due to the buses' old age, obsolete technology, poor maintenance, bad fuel quality, and overloading have increased emissions from buses in India.

In India, buses are manufactured using truck engines and chassis that are not suitable for urban driving conditions. They predominantly consume diesel fuel due to the inherent advantage of efficiency, reliability, and durability. Diesel-fueled vehicles emit a greater amount of oxides of nitrogen (NO_x) and particulate matter (PM) due to high combustion temperature. NO_x contributes to ozone formation, and diesel PM especially particles of less than 10 microns in diameter are carcinogenic in nature. A study by Kirchstetter et al. (1999) found that heavy-duty diesel vehicles emit 15–20 times more particles when compared to light-duty vehicles. There are several studies that have characterized the health and environmental impacts of diesel exhaust and other particulates (Mohanraj and Azeez, 2004; Hoek et al., 2010).

1.1. Need for exclusive driving cycles

Driving cycle is a sequence of operating conditions (idle, acceleration, deceleration, and cruise) developed to represent a typical driving pattern of a city. In India, driving cycles are adopted from Europe. Hence, for the purpose of type approval, certification of vehicles, and to estimate exhaust emissions European testing procedures are employed. Heavy-duty engines are tested on an engine dynamometer in a steady state condition using the Economic Commission for Europe Regulation No. 49 (ECE R49) procedure for the purpose of certifications. The test is comprised of 13 sequence modes defined by different settings of speed and load. The main reason for not testing the complete vehicle is that certain engines are used for different applications. As the name indicates, emissions are measured at fixed speed/load operating conditions.

The major limitation of the steady state test is that it does not capture the transient conditions changing from one operation to another. Hence, from 2010 onwards, Euro III buses are required to certify under the European Transient Cycle (ETC) in addition to the

* Corresponding author. Tel.: +1 949 701 8217; fax: +1 949 824 8385.
E-mail addresses: ksnesa55@hotmail.com (K.S. Nesamani), kps_subbu1@yahoo.co.in (K.P. Subramanian).
[1] Tel.: +91 44 22581603.

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European Stationary Cycle (ESC). The ESC is similar to the ECE R49 test except that load and weight factors have changed. ETC is based on the real-world measurement in Europe that captures three driving patterns, including urban, rural, and motorway. The total cycle period is 1800 s with each driving pattern 600 s (Arregle et al., 2006). These tests are supposed to represent real-world driving conditions and create repeatable measurements, but in reality, none of these driving cycles represents Indian traffic conditions. Therefore, developing exclusive driving cycles is an indispensible requirement to enable better estimation of emissions and fuel consumption.

Vehicle design, traffic characteristics, geometric design, and roadside environment in general strongly affect emissions per kilometer (Ericsson, 2000; Nesamani et al., 2007). Hence, ARAI (Automotive Research Association of India) in India has developed a facility to measure the fuel consumption and mass emissions of in-use heavy-duty vehicles using the chassis dynamometer. ARAI has developed two heavy-duty driving cycles, Delhi Bus Driving Cycle (DBCD) and an Overall Bus Driving Cycle (OBDC) based on data collected in Delhi as shown in Fig. 1. Both driving cycles have similar characteristics with time periods of 170 and 150 s respectively (Badusha and Ghosh, 1999; ARAI, 2007). However, these cycles are developed with constant speed and acceleration profiles, which do not reflect real-world driving patterns. Pelkmans et al. (2001) found that real-city traffic and simulated city cycles differ from technology to technology. Therefore, researchers have focused on measuring the real-world emission using the on-board measurement system. From Euro VI regulation onwards, it is required to verify real-world emissions using the portable emissions measurement system. Table 1 shows the timeline to implement the emission standards for heavy-duty vehicles in India and the European Union. It shows that India is lagging behind about eight to 10 years in implementing these standards.

Several efforts have been made recently in India to analyze driving characteristics of light-duty vehicles (two-wheelers, cars) in various cities (Nesamani and Subramanian, 2006; Kamble et al., 2009). However, the knowledge of bus driving characteristics in India is very limited. Therefore, the main objective of this study is to examine operating characteristics of intra-city buses in Chennai, India using Global Positioning System (GPS). The second objective is to develop a driving cycle based on data collected second-by-second and to compare mean values of newly developed driving characteristics with those for conventional and common driving cycles. Long-distance buses are not considered as part of this study since they have different operating conditions.

2. Methodology

Fig. 2 illustrates the methodology adopted in this study to analyze the driving characteristics of intra-city buses. Different parameters used to describe the driving characteristics were identified from the literature review as a first step. The second step was to estimate and analyze the mean value of the driving characteristics of test runs. The third step was to develop a driving cycle using the micro-trips derived from test runs. The fourth step was to develop the speed-acceleration frequency distribution (SAFD) as suggested by Watson et al. to analyze the distribution of speed and acceleration of developed cycle (Watson, 1995). The last step was to compare the estimated driving characteristics with the international driving cycles of urban buses and analyze the differences. Chennai city was selected as the case study area and GPS was used to collect the speed and acceleration profile of buses.

The various parameters identified from the literature review to describe the driving characteristics are as follows,

- Average speed (V_1) – Average speed of entire trips (km h^{-1})
- Average running speed (V_2) – Average speed of entire trips excluding idle time (km h^{-1})
- Maximum speed (V_{max}) – Maximum speed of entire trips (km h^{-1})
- Average acceleration (Acc) – Average acceleration of entire trips (m s^{-2})
- Average deceleration (Dec) – Average deceleration of entire trips (m s^{-2})
- Maximum acceleration (Acc_{max}) – Maximum acceleration of entire trips (m s^{-2})
- Maximum Deceleration (Dec_{max}) – Maximum deceleration of entire trips (m s^{-2})
- Percentage of time spent in idle mode (P_i) – Speed equals zero (%)
- Percentage of time spent in acceleration mode (P_a) – Speed greater than 5 km h^{-1} and acceleration greater than 0.1 m s^{-2} (%)
- Percentage of time spent in deceleration mode (P_d) – Same as acceleration except that acceleration should be negative (%)
- Percentage of time spent in creeping mode (P_{cr}) – Speed less than 5 km h^{-1} and acceleration and deceleration should be less than 0.1 m s^{-2} (%)
- Percentage of time spent in cruise mode (P_c) – Speed greater than 5 km h^{-1} and acceleration and deceleration should be greater than 0.1 m s^{-2} (%)

Table 1
Implementation of emission standards for heavy-duty vehicles in India and the European Union.

Emission standards	India			European Union
	NCR (National Capital Region)	Major cities	Nationwide	
Euro I	2000	2000	2000	1992
Euro II	2001	2003	2005	1996
Euro III	2005	2005	2010	2000
Euro IV	2010	2010	Not yet decided	2005
Euro V	Not yet decided	Not yet decided	Not yet decided	2008
Euro VI	Not yet decided	Not yet decided	Not yet decided	2013

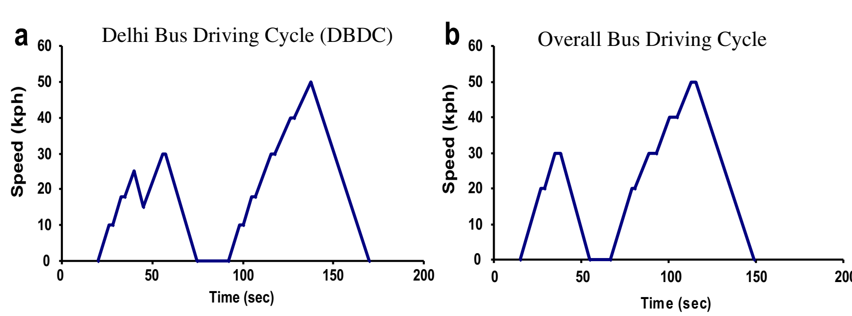

Fig. 1. In-use heavy-duty driving cycles in India.