

On-Road Vehicle Driving and Energy Requirements and Impact on Unregulated Exhaust Emissions under Urban Driving Conditions

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ABSTRACT

The standard emission protocol including driving cycle is performed for the legislative fuel economy and emission testing of the vehicles in a laboratory. The driving cycles are expected to represent actual driving pattern and energy requirements. However, recent studies showed that the gap between real world driving conditions and the standard driving cycle is widening, as the traffic pattern and vehicle population is varying dynamically and the change in the emission procedures is not synchronized with the same pace. More so, as the process of harmonization of emission legislations is in progress to narrow down the country specific variation of emission regulation, as this will help in the smooth globalization of the automotive business process. The new regulation for in-service conformity is being considered to reduce the emissions in real-world driving. It is important that the new procedure should represent the on-road driving and energy requirements in a better way than the current procedures. This study compares the potential of presently used Modified Indian Driving Cycle (MIDC) and proposed (WLTC) emission test cycle towards assessment of key real-world driving parameters like positive kinetic energy, relative positive acceleration, and speed acceleration pattern, etc. The real world driving trips were performed in the urban area in the different traffic conditions of the day. The impact of real world driving trips on the unregulated emissions (Benzene, aldehydes, and butadienes, etc.) was estimated by International Vehicle Emission models. The Emission results of the currently used driving cycle and the new world harmonized cycle are also compared with the real world estimation to evaluate the potential of both the cycles for the representation of the real world driving and unregulated emissions from gasoline-fuelled light duty passenger cars, considering urban traffic conditions. Driving parameters were mathematically calculated and compared with standard test cycles. Real world driving trips were found dispersed in wide acceleration/deceleration range and runs at lower average speed than both the standard cycles. The WLTC shows around 50% less deviation of relative positive acceleration (RPA) with real world driving as compared to MIDC. However, the average speed of MIDC was observed about 8% closer to real world driving average speed in comparison to WLTC. The butadienes emission were observed around 60~80% higher in real world driving condition as compared to MIDC and WLTC cycles.

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INTRODUCTION

The share of the world's population living in urban areas will grow to nearly 70 percent by 2050 and energy consumption for transport needs in cities is expected to be much higher, which has already doubled in last 30 years [1]. The light duty vehicles will continue to drive the growth and currently consuming around 20% of the total oil consumed in transport sector [1]. The high fuel consumption and emissions affect the air quality and consequently the human health and environment. The World Health Organization (WHO) has estimated that urban air pollution is responsible for approximately 1.1 million deaths around the globe [2]. Vehicle emission standards are the primary technical policy tools available for mitigating emissions from vehicles. The emission test procedures for the light duty

vehicles are based on a transient cycle representing a driving pattern of a particular country. The light duty vehicle cycle FTP-75 and NEDC are used in the US and Europe as a test procedure, respectively [3]. The China and India are following the NEDC for light duty vehicle emission measurements [4]. The real world driving pattern is a highly dynamic process, and it was found during early 1990's that the FTP-75 test cycle does not cover more than 15% of driving conditions and behavior encountered in real life operation such as aggressive driving and driving immediately after cold start [5]. Therefore, the development of a real-world driving cycle is important for traffic and transport management, on-road vehicular fuel consumption and emission reductions [6, 7]. Various countries have developed driving cycles to analyze different aspects and impacts of local driving conditions, as summarized in Table 1.

Table 1. Research on driving cycles across the world

Country	Researcher	Aim
China	Wang et al., 2008 [8]	Driving cycle development and comparison with European and US cycles
Canada	Seers et al., 2015[9]	Development of two driving cycles for utility vehicles
UK, South Korea	Birrell et al., 2014 [10]	Analysis of three independent real-world driving studies
South Korea	Han et al., 2012[11]	Characterization of driving patterns and development of a driving cycle in a military area
UK	Kumar et al., 2011[12]	Comparison and evaluation of emissions for different driving cycles of motorcycles
China	Tong et al., 2011[13]	Development of driving cycles for motorcycles and light-duty vehicles in Vietnam
Vietnam	Tung et al., 2011[14]	Development of emission factors and emission inventories for motorcycles and light duty vehicles in the urban region
China	Peng et al., 2015[15]	Construction of Engine Emission Test Driving Cycle of City Transit Buses
India	Nesamani et al., 2011[16]	Development of driving cycle for intra-city buses

These studies bring out the significant difference between certification cycle and real-world driving cycle regarding key driving parameters. The representativeness of a driving cycle is evaluated by computing the deviation of the main driving parameters such as average velocity, average positive acceleration, stops per distance and positive kinetic energy, etc. In the development of driving cycles, efforts are made to keep deviations as minimum as possible. The difference between these parameters for a regulatory driving cycle and real-world driving cycles is the main reason for the gap between real world fuel economy and type approval data [17].

Some studies have been carried out to assess the gap between certification and real-world fuel economy and emissions. An ICCT study compared emission of diesel cars on the road with Euro VI limits and certification testing [18]. The study concluded that modern diesel passenger cars have low on-road emissions of carbon monoxide (CO) and total hydrocarbons (THC), but an unsatisfactory real-world emission profile of nitrogen oxides (NOx). The average, on-road emission levels of NOx were estimated at seven times the certified emission limit for Euro 6 vehicles. European Commission has been particularly active in addressing the gap between real world driving emission and regulatory procedure and started the activity under the 5th Framework Programme of the European Commission under DECADE project, using intensive measurements on engine dynamometers, chassis dynamometers and in real traffic experiments have established that most of the emissions measured in the certification cycle differed dramatically from the actual traffic emissions [19] (Pelkmans et al., 2006). The recent updates from

European Commission stated that Euro 6 emission standards have led to significant drops in emissions of exhaust PM and other pollutants such as HC and CO. However, NOx emissions, and in particular NO2 emissions, from road transport have not been reduced as much as expected with the introduction of the vehicle Euro emissions standards, since emissions in real-life driving conditions are often higher than those measured during the approval test [20,21,22]. To control high on-road emissions from passenger vehicles, where a significant gap with the laboratory testing has been confirmed in recent years [23, 24, 25, 26, 27], the Commission is introducing the Real Driving Emissions test procedure (RDE) starting from 1 September 2017, which will accurately estimate the actual emissions on the road and narrow down the current discrepancy between emissions measured in real driving to those measured in a emission measurement laboratory as per regulatory procedures.

In India, the Indian Driving Cycle (IDC) was developed in 1985 [28]. Further important studies were undertaken consequently [28, 29, 30, 31, 32, 33, 34]. However, limited studies have been conducted, in India, to understand the difference between real world fuel economy and emission as compared to certification data. The study carried out in Chennai revealed that Indian driving cycle does not represent real world driving and emission were estimated almost two times higher in the real world as compared to IDC [34]. The study on auto rickshaws running in Delhi also concluded that the IDC underestimates fuel consumption and emissions as compared to on-road driving emissions [32]. In Real-world driving, auto-rickshaws consumes approximately 15% more fuel and emit around 49% more total hydrocarbons (THC, C₁ equivalent) and contribute to 16% more particulate matter with aerodynamic diameter less than 2.5µm (PM_{2.5}). The study on real-world fuel economy on Dehradun-Delhi highway and Delhi-Jaipur highway concluded that the real world fuel economy in two different highways was significantly different from certification values [35]. The data from the study also established that current practice underestimates the emission rates as compared to complex real-world driving conditions.

These studies have mainly followed two approaches. The first approach is to collect driving data from the real world using GPS or ECU and compress the data in such a way to form a representative cycle (about 20-30 min) by maintaining a close deviation (<5%) to the pool data acquired in real world driving trips. This approach has a limitation of moderately representing the real world driving condition as based on different considerations, hundreds of hours of driving data are compressed to few minutes, and the very high acceleration and sudden braking conditions can't be satisfactorily simulated on a chassis dynamometer. The compressed driving cycle represents a compromise of different driving parameters and laboratory limitations and often deviates significantly from real world conditions. The second approach is to use portable emission analyzer (PEMS) onboard and collect the real world driving condition and emissions simultaneously. This method also has certain limitations. The PEMS equipment is expensive, and it's not economically feasible to run several vehicles simultaneously and collect data for a large number of trips in a short time. The PEMS along with on-board accessories such as calibration gas cylinders, batteries and fittings, makes it heavy, specifically in the case of small passenger cars and practical life loading is not represented and also, real-world driving

the normal real world driving. Moreover, the testing is time-consuming and expensive. So, it is difficult to acquire data of a large number of trips (to represent all the real world driving condition) in a short time and economically. The above studies have been limited to regulated emissions from vehicles.

Table 2. Usage of Emission Models across the world

Emission Model	Research by	Application
IVEM	Zhang et al. 2011[42]	Comparison of free flow traffic emissions
	Wang et al. 2008[43]	On-Road vehicle emission inventory for Shanghai, China
	Mishra et al. 2014[44]	Estimation of Vehicular Emissions using Dynamic Emission Factors: A Case Study of Delhi, India
CMEM	Nagpure et al. 2011 [45]	Emission estimation of gasoline vehicles in India
	Lents et al. 2004 [46]	Comparison of On-Road Vehicle Profiles Collected in Seven Cities Worldwide
	Davis et al. 2005 [47]	Fleet Emissions in developing countries
COPERT	Lozhkina et al., 2015[48]	Estimation of road transport related air pollution in Saint Petersburg using European and Russian calculation models
	Marmur et al., 2003 [49]	Comparison and evaluation of several mobile-source and line-source models in Israel
	Ganguly et al., 2008 [50]	Performance evaluation and sensitivity analysis of the general finite line source model for CO concentrations adjacent to motorways
MOVES	Jeong et al., 2015 [51]	Emission evaluation of inter-vehicle safety warning information systems
	Wu et al., 2014 [52]	Sensitive analysis of emission rates in MOVES for developing site-specific emission database

The regulated emissions from the vehicles are CO, THC, NO_x and PM (for diesel engine/vehicle). However, unregulated emissions from vehicles, significantly, affect the air quality and strongly influence human health and the atmosphere [36]. The emissions of these unregulated compounds can be sub-classified as air toxic emissions (formaldehyde, acetaldehydes, and ammonia) and GHG emissions (carbon dioxide, nitrous oxide, and methane) [36]. The formaldehyde (HCHO) and acetaldehyde (CH₃CHO) are classified as a probable human carcinogen by the US Department of Health and Human Services [37]. Ammonia (NH₃), which is considered as a precursor of atmospheric secondary aerosol [38, 39] and it is also classified as corrosive, toxic and dangerous for the environment under the European dangerous substance directive (67/548/EEC) [40]. The GHG gasses are responsible for the global warming and the climate change. The formaldehyde (HCHO), acetaldehyde (CH₃CHO) and

nitrogen oxides are also specified as the primary ozone precursors in the air as per the European Air Quality Directive on Ozone, 2002/3/EC [30]. So, it is crucial to study the emissions from vehicles not only the regulated gasses but also the unregulated ones and more so in the real world driving conditions. However, the emission measurement facilities are equipped for the regulated emissions as per legislative procedures and lack of the unregulated emission measurement. The Portable Emission Measurement System (PEMS) technology is also upcoming and limited only for regulated pollutant.

There have been extensive studies on the application of American or European emission models, for example, IVE, CMEM, MOBILE, and COPERT into non-US regions to assess vehicle emissions. (Hoglund et al. [41] have explored and verified the methodology and use of microsimulation to estimate vehicle emissions. The summary of the popular models is given Table 2.

It should be noted that these emission models are designed specifically for US and European regions. Therefore, differences between developing countries like China, India and these developed countries in vehicle operating condition and emission performance will lead to significant emission estimation bias, as the model is not comprehensively revised due to the closed model structure or the lack of valid data. However, above models are useful in estimating the impact of the driving pattern of emissions. For example, IVE model estimates the unregulated emissions like benzene, aldehydes, and ammonia, etc.

The methodology used in present work is unique in the sense that it represents the emissions and characteristics of a no-bias study, real world driving pattern. The driving pattern of the real world is directly fed into emission models, which give reasonable estimates of every trip, thus accounting for different aspects such as driver aggression and traffic conditions, without being biased towards certain regions of driving behavior or restricted by laboratory equipment. The emission estimated and the cycle parameters calculated are compared by deviation from certification cycles.

In this study, urban road cycles were compared with MIDC and WLTC standard cycles, respectively, the current and future certification standards. MIDC is the current standard emission test cycle for India, adapted from NEDC by lowering maximum speeds. Worldwide Harmonized Light Vehicles Test Procedure (WLTP) is being developed by a collaboration of several countries across the world including the European Union, India and China and is expected to serve as a universal test parameter. It is designed to incorporate driving patterns from across the world and represent road conditions everywhere. Thus it becomes critical to analyze this cycle keeping in mind future development of emission regulation. However, due to standardization, a gap is created from the individual characteristics of each country. Moreover, typical driving patterns focus on large urban cities like Mumbai in India. However, Tier-II cities have significantly different driving conditions and are expected to dominate road emissions in India. This work aims at quantifying the gap between WLTC and road conditions in such urban centers in India.

METHODOLOGY

The test vehicle fleet was selected considering the market share of the make and model of light duty gasoline passenger cars. The test vehicles (12 nos) were instrumented with global positioning (GPS) system and for collecting on-road driving data. The vehicles were driven by selected routes and GPS files containing speed, latitude, longitude, and altitude were stored on a flash drive for post analysis of the data. These GPS files were analyzed for various driving parameters such as PKE, RPA and stops per kilometer by a Matlab program which was also prepared during this study. The International Vehicle Emission Model was used to estimate the real world unregulated emissions based on the real world driving trips as input parameters. The Vehicle category was selected based on the test vehicle for simulation with IVE model. The real world driving parameters and simulated emissions were compared with standard driving cycles (MIDC and WLTC). The methodology in the flow of the activities of this work is given in Figure 1.

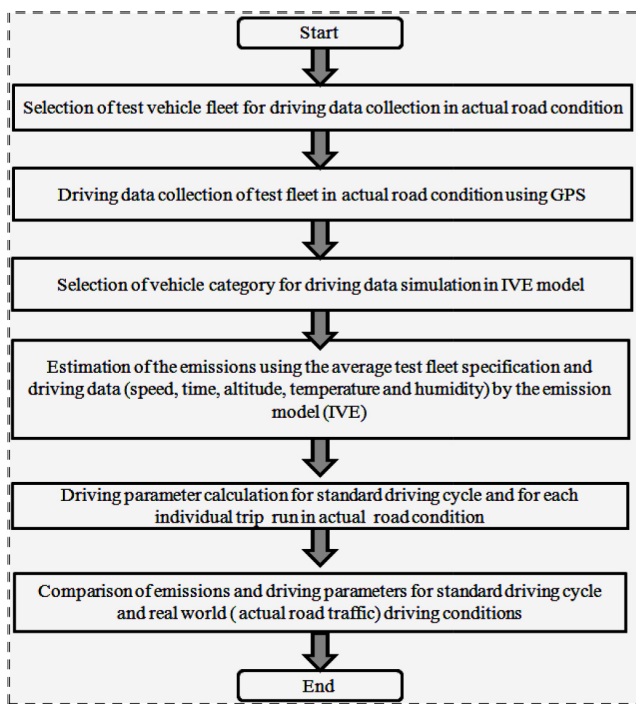


Figure 1. Methodology of the present work

Test Vehicles

The specifications of the test vehicle fleet for driving data acquisition are given in Table 3. The vehicle category for simulation was selected based on the specifications of the test vehicle.

Road Cycle Acquisition

Light gasoline passenger cars with curb weights in the range of 1000 to 1200 kg were used to collect on-road driving data. The car-chasing technique was used to acquire the driving patterns of cars. Professional drivers were employed to drive cars to follow the traffic in defined routes and specially-designed instruments were used in the cars to store the vehicle speed second-by-second. A set of parallel equipment - a Global Positioning System (GPS) receiver and a speed sensor was used for data quality control purpose. Three representative

routes specifically representing congested, medium and lean traffic conditions in a typical Indian city was selected for the data collection are shown in Figure 2.

Table 3. Specification of test vehicles

Vehicle Fleet	Type 1 (Alto)	Type 2 (Wagon R)	Type 3 (Hyundai Accent)	Type 4 (Swift dezire)
Fuel	Gasoline	Gasoline	Gasoline	Gasoline
Emission Type	Euro IV	Euro IV	Euro IV	Euro IV
Engine Capacity, cc	998	998	1086	1197
Compression ratio	10.0:1	9.1:1	8.9:1	11.1:1
Maximum Power	68 PS @ 6000 rpm	68 PS @ 6000 rpm	62 bhp @ 5500 rpm	84.3 PS @ 6000 rpm
Maximum Torque	90 Nm @ 3500 rpm	90 Nm @ 3500 rpm	96 Nm @ 3000 rpm	115Nm@4000 rpm
Kerb weight, kg	750	870	854	965
Gross vehicle weight, kg	1210	1350	1250	1415
Catalyst	TWC	TWC	TWC	TWC

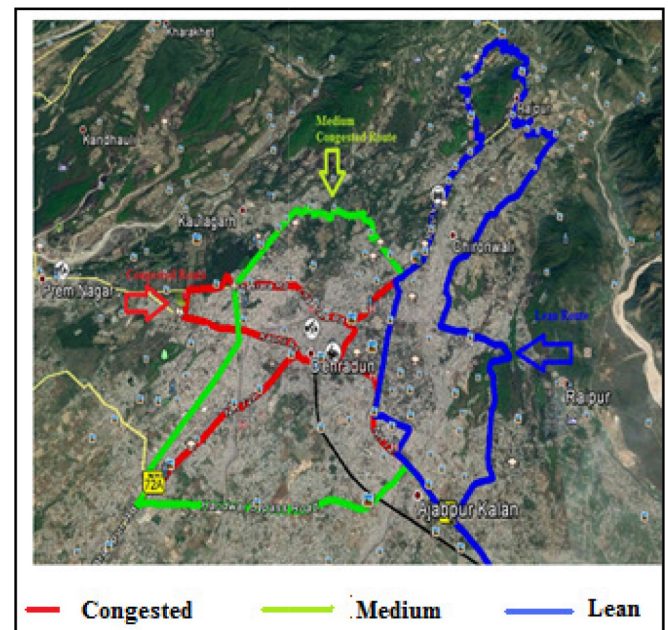


Figure 2. Experimental routes for collection of road cycles in different traffic conditions

To represent daily road activity, trips were conducted during the entire active traffic hours of the city. The time of test trips was classified as rush hours and off-peak (Figure 3). The numbers of trips were carried out as almost twice in peak hours as compared to off-peak hours.

