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Developing Singapore Driving Cycle for passenger cars to estimate fuel consumption and vehicular emissions

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HIGHLIGHTS

- Lack of a realistic driving cycle to evaluate energy and emissions in road transport.
- Develop a representative driving cycle for passenger cars in Singapore.
- Methodology incorporate multi-levels of representativeness – distance, road type, peak, lull.
- Representativeness characteristics are determined from extensive surveys and data collection.

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ABSTRACT

Singapore has pledged to attain 7–11% Business-As-Usual carbon emissions reduction by 2020. Road transport sector is a significant source of carbon emissions, estimated to be the third largest sector in Singapore. A current gap in environmental evaluation for road transport activities in Singapore is the lack of a representative driving cycle for passenger cars (64% of the total population of 974,170 vehicles). This Singapore Driving Cycle (SDC) is hence developed for Singapore roads and traffic conditions. A chase-car (instrumented vehicle) was used to collect on-road data along 12 designed routes, and circulation driving on highly utilized arterial roads (including those in Central Business District (CBD) and both inner and outer ring roads fringing the CBD area). The SDC was thus hence constructed, with consideration of road type proportions, time periods and desired distance, duration and peak-lull proportion. In essence, the SDC is a 2400-s speed–time profile to represent the driving pattern for passenger car in Singapore. Microscopic estimation model (CMEM) shows that, as compared to SDC, the New European Driving Cycle (NEDC) underestimates most of the vehicular emissions (fuel, CO_2, HC and NO_x by 5%, 5%, 22% and 47%, respectively) and overestimates CO by 8%. The SDC is thus more suitable than the NEDC that is currently in use in Singapore; the SDC can be used to generate more accurate fuel consumption and emissions ratings for various uses (for example, inventory of vehicular emissions and fuel economy labelling).

1. Introduction

1.1. Overview

Ever since the Fifteenth session of the Conference of the Parties (COP-15 in 2009) session held by The United Nations Climate Change Conference till COP-18 (in 2012), Singapore had reiterated her commitment to achieve 7–11% below Business-As-Usual (BAU) carbon emissions by 2020 as unconditional pledge in the absence of a legally binding global agreement (Singapore's National Statement, 2011) and full commitment to a 16% below BAU pledge in presence of a legally binding agreement (Singapore's National Statement, 2012). In Singapore, the top three energy consumers are electricity generation, industry and road transport. However, it is difficult for electricity generation and industry to reduce significantly without affecting the economy. Therefore, road transport is a key area to work towards mitigating climate change. International Energy Agency (IEA) consolidated statistics shows that Singapore road transport sector produced 7.18 million tonnes of CO_2 in 2008 and 8.17 million tonnes of CO_2 in 2009, indicating a 78.3% (Year 2008) and 102.9% (Year 2009) increment from 1990 (International Energy Agency (IEA), 2010; International Energy Agency (IEA), 2011). Currently, Singapore has yet to establish her

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national inventory of greenhouse gases (GHGs) and associated air pollutants from anthropogenic activities such as road transport. In time to come, national inventory will be in place to facilitate downstream applications such as mitigation reduction targets and quantifications. This is also important in terms of air quality – air pollution management.

Passenger car population reached 392,961 in 2000 and increased to 617,570 in 2012, translating to a 57% growth within a 12-year span (Land Transport Authority (LTA), 2013). Passenger car population forms about 64% of the total vehicle population, with an average annual mileage of 19,000 km in 2011 (Land Transport Authority (LTA), 2012). Hence, the passenger car was chosen as the focus vehicle type for evaluating the impact of road transport on the environment. On the other hand, remaining 36% of the vehicles (buses, goods vehicles and motorcycles) are diverse in their classification and trip making patterns. These differences require incorporating minute details in constructing their driving cycles, which in turn, are of lesser urgency than the need of a single driving cycle for the passenger car.

1.2. Motivation: the need to develop Singapore Driving Cycle (SDC)

In Singapore, the driving cycle in use to date for testing in a laboratory setting is the New European Driving Cycle (NEDC). Being a synthesized cycle of artificially jointed mode of operations (cruising, accelerating, decelerating and idling), NEDC is not well representative of the driving conditions in a highly urbanized island-state like Singapore. The lack of a representative local driving cycle is a critical gap that warrants urgent action. It is also clear that driving cycle-related applications such as fuel consumption and vehicular emissions are dependent on the quality of applicable driving cycle. In essence, the use of ill-fitting driving cycles would not allow derivation of accurate estimations. Moreover, estimations should not be based solely on average speeds as in NEDC's case as the proportion of speed changes, accelerations and idling are critical as well. Alongside with vehicular emissions, harmful air pollutants are emitted. The emission inventory is then dependent on the accurate emission rates that are in turn to be derived from a representative driving cycle.

Besides NEDC's inability to characterize the speed changes, it is also not designed to match the modes of operation (percentages of idling, acceleration, deceleration and cruising) as well as maximum and average speeds. The proportions of expressway and arterial roads coverage in a trip will be indigenous to the road network; in Singapore, the road network is concentrated within a small nation of 710 square km, and peak period and lull period characteristics are also quite different. Hence, the NEDC is not well suited for use in Singapore.

In this paper, the authors formulated an unique driving cycle framework covering in-depth study of data collection methods, route selection, cycle construction and data analysis. The results are representative of Singapore's road network and drivers' trip making patterns (trip distance, expressway-to-arterial proportions, peak-to-lull proportions and trip duration). The finalized driving cycle, known as SDC, is presented. Comparisons are also made with the generic driving cycle, NEDC, whereby its unsuitability is highlighted. Estimations of fuel consumption and emissions are also computed via modelling the passenger car population in Singapore.

2. Literature review

2.1. Overview of driving cycle framework

In a broad sense, driving cycles are essentially driving patterns that are synthesized to indicate real-world driving in an average sense. Such synthesized driving cycles are structured as speed–time profiles that constitute snippets of different modes of operations joined up sequentially; these driving cycle constructs are also known as modal driving cycles. Synthesized cycles include the New European Driving Cycle (NEDC) of 69 modes, Japanese driving cycles (10-mode and 15-mode) and California seven-mode cycle (Montazeri-Gh and Naghizadeh, 2003; Kamble et al., 2009; Lee et al., 2010). Real-world driving cycles are derived from actual trip data on the roads. Various real-world driving cycles in use are ARTEMIS European driving cycles, Urban Emissions Drive Cycles (UEDC), Bangkok Driving Cycle, Hong Kong Driving Cycle, Kaohsiung Driving Cycle, Athens Driving Cycle, FTP-75 Driving Cycle, LA92 Driving Cycle, SC03 and US06 driving cycles (Brown et al., 1999; Tong et al., 1999; Montazeri-Gh and Naghizadeh, 2003; Tsai et al., 2005; Karavalakis et al., 2007).

2.2. Data collection

From literature survey, data collection can be categorized into three methods, namely (1) chase-car method (instrumented car to collect data as it follows randomly selected vehicles); (2) on-board measurement methods (instruments installed in subject vehicles to collect their trip activities); and (3) combined method of chase-car, on-board measurement and circulation driving (instrumented car driven during the lull and peak periods on pre-selected routes) (Niemeier et al., 1999; Tong and Hung, 2010; Zhang et al., 2012).

The chase-car method involves a random selection of a target vehicle in the traffic stream and the chase-car follows this target vehicle and keeps a constant distance during cruise conditions and allowing a time lag for both acceleration and deceleration phases (Kent et al., 1977). Real-world driving cycles derived directly from the chase-car method includes Bangkok Driving Cycle (BDC), Hong Kong Driving Cycle (HKDC), Edinburgh Driving Cycle (EDC), Sydney Driving Cycle and Pune Driving Cycle. The Bangkok Driving Cycle was constructed using data collected during peak periods via a chase-car equipped with data logger capturing speed–time profiles, similarly for the case of the Hong Kong Driving Cycle which also included instrumented vehicles' records (Tong et al., 1999; Hung et al., 2007; Tamsanya et al., 2009). In the United States, chase-car data have been widely used to derive driving cycles (Morey et al., 2000; Lin and Niemeier, 2003b). Unified Cycle (LA92 Driving Cycle) was developed using chase-car data comprising 102 runs with second-by-second speed data (Lin and Niemeier, 2002). In Europe, several studies have used the chase-car technique as well (Esteves-Booth et al., 2001).

On-board measurement technique is considered as instrumented vehicle. The instrumented technique is often coupled with chase-car method, as seen in driving cycles developed in South Korea, Delhi and Malaysia. The South Korean driving cycle in a military area was developed using both methods to enable capturing hard accelerations and decelerations as military routes involved unpaved surfaces. Global Positioning System (GPS) data were the basis of the vehicle speed (Dong et al., 2012). On the other hand, Dublin driving cycle was developed from data collected via on-board diagnostic reader (OBD II) that extracts vehicle data including OBD speed, engine speed, coolant temperature and engine load during the recorded runs conducted over a period of 3 days whereas Delhi instrumented vehicles made four runs per day for six days a week (Achour et al., 2011; Chugh et al., 2012). The ARTEMIS European driving cycles were developed with a fleet of 58 instrumented vehicles with 73,000 km covered in a total of 1400 days (André, 2004). The Australian urban emissions drive cycles (UEDC) were developed using the on-board measurement for diesel-powered vehicles (Brown et al., 1999).