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Development of simulated driving cycles for light, medium, and heavy duty trucks: Case of the Toronto Waterfront Area

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ABSTRACT

Driving cycles are an important input for state-of-the-art vehicle emission models. Development of a driving cycle requires second-by-second vehicle speed for a representative set of vehicles. Current standard driving cycles cannot reflect or forecast changes in traffic conditions. This paper introduces a method to develop representative driving cycles using simulated data from a calibrated microscopic traffic simulation model of the Toronto Waterfront Area. The simulation model is calibrated to reflect road counts, link speeds, and accelerations using a multi-objective genetic algorithm. The simulation is validated by comparing simulated vs. observed passenger freeway cycles. The simulation method is applied to develop AM peak hour driving cycles for light, medium and heavy duty trucks. The demonstration reveals differences in speed, acceleration, and driver aggressiveness between driving cycles for different vehicle types. These driving cycles are compared against a range of available driving cycles, showing different traffic conditions and driving behaviors, and suggesting a need for city-specific driving cycles. Emissions from the simulated driving cycles are also compared with EPA's Heavy Duty Urban Dynamometer Driving Schedule showing higher emission factors for the Toronto Waterfront cycles.

Introduction

Driving cycles are an important input for state-of-the-art vehicle emission models. Driving cycles have been developed for various cities and vehicle types. A driving cycle is a representative speed-time profile for a study area within which a vehicle can be idling, accelerating, decelerating, or cruising. However, speed-time profiles vary across cities due to each city's unique topography and road driving behavior and they have been shown to vary by vehicle type, time of day and type of road (Ericsson, 2001; Hung et al., 2007; Kamble et al., 2009; Saleh et al., 2009; Yu et al., 2010).

Two categories of driving cycles can be found in the literature: First, synthesized (or model) driving cycles which are built from combining different phases of idling, constant acceleration/deceleration and steady speed. Examples include the European cycle (NEDC) and the Japanese cycle (J10-15). However unrealistic transition between the different phases in these driving cycles could result in erroneous emission estimation (Chugh et al., 2012; Kamble et al., 2009; Pelkmans and Debal, 2006; Tong and Hung, 2010; Weiss et al., 2011).

Second, real world driving cycles (or transient driving cycles) are developed by recording speed-acceleration profiles while driving on the real world roadway network. In other words, these cycles are synthesized from real-world speed data. Examples include FTP-75 in the US, and driving cycles for Pune (Kamble et al., 2009), and Hong Kong (Hung et al., 2007).

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No real world driving cycle has been developed for the Toronto area. The only recent driving cycles developed for the Toronto area were synthesized using CALMOB6 reflecting average speeds from a travel demand model using the Transportation Tomorrow Survey (TTS) (Raykin et al., 2012).

The objective of this paper is to develop representative simulated driving cycles, using simulated data, for different combinations of roadway class, time of day and vehicle attributes. There are several applications for a disaggregate set of driving cycles. Emissions and fuel consumption impacts of changing congestion patterns, peak spreading, new infrastructure, and vehicle specific driving behavior could be better addressed. The emissions benefits of new vehicle technology could be assessed more specifically for different roadway types (e.g. when and where would the greatest benefits of plug-in hybrid electric vehicles be attained?). Vehicle routing algorithms could be developed that include congestion-sensitive fuel consumption and emissions in the objective function, for example, to service congested areas with lower emitting vehicles during off-peak hours.

Background and motivation

A driving cycle is made up of micro-trips where a micro-trip is defined as the trip between two idling periods. A driving cycle is usually for a 10–30 min interval, which is long enough to contain enough micro-trips to reflect the diversity of real world driving behavior, but short enough to be practical and cost effective in terms of data collection (Hung et al., 2007; Lai et al., 2013; Yu et al., 2010).

Development of a driving cycle generally involves three steps: test route selection, data collection, and cycle construction. Test route selection involves selecting the route on which data are to be collected. The data collection step generally involves the collection of the speed of a sample of vehicles at frequent time intervals (usually on a second-by-second basis) using the car-following method, or on-board measurement using GPS devices (Chugh et al., 2012; Coelho et al., 2009; Green and Barlow, 2004; Han et al., 2012; Hung et al., 2007; Kamble et al., 2009; Prasad et al., 2012; Shahidinejad et al., 2010; Sriniwas et al., 2011; Tzirakis et al., 2006; Wang et al., 2008; Yu et al., 2010).

Cycle construction consists of 5 steps: (1) define the set of assessment measures used to describe a driving cycle; (2) calculate the assessment measures for the collected data (called target statistics); (3) develop a candidate driving cycle from the pool of micro-trips available (called candidate cycle); (4) calculate the same assessment measures for the candidate cycle (called test statistics); and (5) identify the candidate cycle whose test statistics are closest to the target statistics.

The studies in the literature are distinguished based on how the candidate driving cycles are developed, and the set of assessment measures used for comparison. Most of the studies in the literature have used random selection of micro-trips as the method for producing a candidate cycle (Hung et al., 2007; Kamble et al., 2009; Wang et al., 2008; Xiao et al., 2012). A few studies have used the driving data clustering method (Fotouhi and Montazeri-Gh, 2013), where micro-trips are first divided into different categories (or clusters) based on their "traffic conditions" (e.g., congested, free flow) and driving cycles are then developed for each cluster. This method is similar to the random selection method, since clustering only results in developing unique driving cycles for each road type or traffic condition. Yu et al. (2010) used a genetic algorithm for part of the cycle development, where micro-trips are first sorted based on their assessment measures. Then the top 20% of micro-trips are selected and a lower and upper limit for the number of required micro-trips in a driving cycle is estimated. A genetic algorithm is then used to develop candidate driving cycles for each number of micro-trips in the cycle (between the upper and lower level). Finally, the cycle with the best performance according to an assessment measure is selected as the final driving cycle. Although this method improves slightly upon the random selection method, the large computational time for a 20% sample of the micro-trips is prohibitive. Consequently, in this research, the random selection method is chosen.

The other difference between studies is the type and number of assessment measures used. Driving activity measures and the Vehicle Specific Power (VSP) method have both been used in the literature. Activity measures refer to statistics like speed and acceleration (Hung et al., 2007; Wang et al., 2008). The VSP method, which is a bin based method, focuses on instantaneous power per unit of a vehicle and is a nonlinear function of instantaneous speed, instantaneous acceleration and road grade (Coelho et al., 2009; Yu et al., 2010). The driving activity measures method has been used in this research for cycle construction as it is used more extensively by researchers in the area making the results comparable to the existing body of literature. The method is described in detail in "Methodology for developing the driving cycles".

This research is motivated by the fact that collection of real world data to develop driving cycles for different vehicles and road types, for a large enough representative sample of vehicles, would either be too costly or biased (if data were collected on a day with unusual congestion patterns). A new method for developing simulated driving cycles is introduced using traffic simulation. This concept has also been studied by Della Ragione and Meccariello (2010), who evaluated the ability of four car-following models to produce simulated driving cycles using data from four vehicles equipped with GPS in the Naples Metropolitan Area. Their results showed that most of the models produce driving cycles and emission values close to the observed; however concluded that further calibration and investigation is required.

Simulated driving cycles use simulated data, collected for all vehicles under consistent and calibrated traffic conditions, from a microscopic traffic simulation for cycle development. In other words, the test route selection step is not necessary for simulated driving cycles, since data can be collected on all routes within a desired roadway classification. Using data from multiple simulation replications also accounts for stochastic variations in traffic conditions, allowing a driving cycle to be more representative. It also allows for analysis of the changes to the driving cycle as a result of future traffic conditions