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A Synthesis of Methodologies and Practices for Developing Driving Cycles

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Abstract

Transportation related emission is the dominant contributing source of air pollutants today. Considering the negative impacts of transportation related emissions on our social and economic environment, extensive efforts have been made by researchers and practitioners attempting to quantify the emissions. Driving cycle is an important concept in emission estimation models. In order to synthesize the research efforts, a comprehensive review of existing methodologies and practices for developing driving cycles is provided followed by a summary of the review results.

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Keywords-transportation; emission; driving cycles; driving schedules; MOVES; MOBILE

1. Introduction

Accurate modeling of transportation emissions is the basis for developing and implementing any effective relief and emissions control strategies. In the United States, the research in the field of transportation emissions has gone through a significant advancement since the establishment of Clean Air Act (CAA) in 1970 and its amendments in 1977 and 1990. The current emission modeling system is composed of a number of models, developed by different agencies, which are used to estimate and predict transportation emissions at different levels (macroscopic, mesoscopic, and microscopic). There exist no emission models and I/M program in China currently [1]. By the nature of different modeling approaches, existing models can be classified into two categories: fuel-based and travel-based models.

The fuel-based models directly utilize fuel use data, which are available from tax records as the traffic database to estimate GHG emissions based on the emission factors expressed in grams per unit fuel

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consumed. The emission factor can be obtained by traditional in-laboratory dynamometer emission measurement or other measurement technologies, for instance Remote Sensing Devise (RSD). A typical fuel-based model, the Computer Programme to Calculate Emissions from Road Transport (COPERT), was developed by the European Environment Agency (EEA) in 1985. Without including transportation activity information, fuel-based models are widely used in energy sector and focus on the relationship between the fuel consumption and emissions.

Different from fuel-based models, travel-based emission models combine the emission factors in certain regions with a region's travel data to generate emission inventories for emission estimations. Being expressed in emissions per unit driving activity, emission factors can be obtained by traditional in-laboratory dynamometer emission measurement or on-road emission testing. Travel data are usually expressed as Vehicle Miles Traveled (VMT).

In the transportation sector in U.S., there are two primary generations of law enforcement transportation emission models currently being used. The models in the first generation include MOBILE developed by USEPA and EMFAC developed by California Air Resource Board (CARB). At present, MOBILE 6.2 (newest version of MOBILE) is approved for use in official SIPs submissions to EPA and for transportation conformity analyses outside of California, while EMFAC2007 (newest version of EMFAC) is approved for use in California. Among all emission species, the emissions in these two emission models are estimated by emission factors which are expressed as grams of emission per unit of distance traveled. Emission factors in MOBILE and EMFAC are determined mostly based on traditional in-laboratory dynamometer tests of predefined or standard driving cycles. A driving cycle, also named driving schedule in the literature, is characterized by a plot of vehicle speed versus time, representing the typical driving behavior or traffic conditions in a given city or region for different vehicle classes.

The second generation model is called MOVES (MOtor Vehicle Emission Simulator), with the newest version MOVES2010 and developed by USEPA, is cycled to ultimately replace MOBILE6.2 for SIPs and for certain transportation conformity analyses outside of California after a two-year grace period according to the publication of Federal Register notice on March 2, 2010.

2. Existing Methodologies and Practices for Developing Driving Cycles

Extensive studies have been conducted in the past on the development of driving cycles, resulting in numerous practical driving cycles in different countries and regions. Examples of existing driving cycles include US FTP-72/75 cycle, CARB unified (LA92) cycle, LA01 cycle, improved European cycles, Athens driving cycle, Perth driving cycle (Australia), Melbourne peak driving cycle (Australia), Sydney driving cycle (Australia), INRETS commercial vehicles driving cycles (France), bus, truck, and composite drive cycles for New York, Bangkok cycle (Thailand), Pune driving cycle (India), German motorway driving cycle, Beijing driving cycles for classified roads, Hong Kong driving cycle, and driving cycles in eleven typical Chinese cities [2]. The full review of existing driving cycles is reported in literature [3].

A common method in developing driving cycles is to screen and select a combination of microtrips that best represent the collected speed-time traces of data. A microtrip is defined as a portion of the speed-time traces of data bounded by an idle mode (zero speed) at both ends. Most of existing driving cycles are developed based on microtrips. Different from microtrips-based approach, LA01 cycle adopts a Monte Carlo simulation approach. The Markov process theory is used in LA01 cycle to describe actual driving process and a new stochastic procedure is introduced in creating driving cycles. Modal events are selected according to the transition probability to form the cycle that matches the target Speed Acceleration Frequency Distribution (SAFD). The basic logic of microtrip-based methodology is a selection of a set of microtrips that closely replicate the trend and characteristics of the whole driving dataset based on predefined performance measures or assessment measures. The selection of performance measures or assessment measures determines the quality of developed driving cycles since assessment measures are the Measure of Effectiveness (MOE) in comparing the trend and characteristics of base data with those of cycles. Another important factor affecting the quality in developed driving cycles is the approach of the development method since it not only determines how selected assessment measures are used to screen final driving cycles from all generated microtrips but also affects the efficiency of the development process of driving cycles. All existing microtrip-based methodology adopts a random or quasi-random method. Reference [3] summarizes some widely adopted cycles in the US, Europe, Asia, and Australia, and lists out their methods for data collection, assessment measures, and development methodologies.

It can be observed from literatures that the typical procedures of current microtrip-based methodology and practice follow the following steps:

2.1 Step1: Data Collection

The second-by second driving activity data are usually collected first for different road types and vehicle classes using a GPS device. Three primary methods have been commonly employed to collect driving data in the current practice, (a) chase car technique, which employs an instrumented car to record the second-by-second speed data as it follows the target vehicles; (b) on-board measurement technique, which installs instruments on target vehicles to record the second-by-second speed data as they travel along the predetermined routes; and (c) combination of on-board measurement and circulation driving, in which a test vehicle with the installation of the instrument travels along selected routes during peak as well as off peak hours for a number of times. The first two methods are widely used in all existing driving cycles except for Beijing driving cycles in which the third method is used.

2.2 Step2: Generation of Microtrips

The development of a drive cycle is based on microtrips. Microtrip is an excursion between two successive time points at which the vehicle is stopped. This part of motion consists of acceleration, cruise and deceleration modes. The whole collected data are separated into a number of microtrips in this step. An example in Figure 2 shows the process of microtrip generation from a portion of collected raw speed data. The segments between two red lines represent the generated microtrips. A large number of microtrips can be obtained after this process is applied to all collected driving activity data. Generated microtrips are to be selected to splice drive cycles in the future steps. This step is conducted by all microtrip-based methodologies.

2.3 Step3: Selection of Assessment Measures

The selection of performance measures or assessment measures is a critical step in the process of developing driving cycles as it determines the quality of developed cycles. The basic idea in the selection of assessment measures is to ascertain that the developed driving cycles can represent the trend and characteristics of the whole driving dataset. A set of measures have been selected in the existing methodologies and practices. It is found that the majority of assessment measures are speed, acceleration/deceleration, and/or portion of driving mode (acceleration, deceleration, cruise, and idling) related parameters. Different methodologies used different forms of these parameters, for example, speed related parameters used include average speed, maximum speed, minimum speed, 95th percentile speed, and root mean square speed; acceleration/deceleration related parameters used include average acceleration/deceleration and average number of acceleration/deceleration changes; and portion of driving mode related parameters used include time proportion of idling mode, time proportion of acceleration, time proportion of cruising and time proportion of deceleration. Other parameters are also used in existing methodologies and practices, for example, Positive Kinetic Energy (PKE) and SAFD. It is found all of these assessment measures are driving activity related information. Different from driving activity related assessment measures, the recently developed Beijing driving cycles incorporated emission factors into assessment measures, which is a brand new idea in the field of developing driving cycles.

2.4 Step4: Development of Driving Cycles

In this step, a set of microtrips are randomly and repeatedly selected from generated microtrips to combine a large number of candidate driving cycles first. Then, the final driving cycle is selected based on the selected assessment measures provided in Step 3. The candidate driving cycle with the least values of assessment measures is usually selected as the final cycle since it can approximately replicate the trend and characteristics of the collected whole driving dataset. With respect to development method, different driving cycles have applied slightly different approaches during this selection. Development methods by some newly developed driving cycles are detailed below.

Pune Cycle [5]: After the selection of assessment measures and generation of microtrips, the Pune cycle first compares all generated microtrips with each other with respect to the assessment measures of the individual microtrips within a tolerance limits ranging from a lower limit to an upper limit. This procedure is to reduce the number of microtrips from the original pool to a very smaller size which can still represent the entire base dataset. The tolerance limits are adjusted based on the desired number of reduced microtrips. Then, a real-world driving cycle is built by selecting multiples of micro-trips from reduced microtrips to match the target assessment measures, namely percent time in acceleration (Pa), percent time in deceleration (Pd), percent time in cruise (Pc), percent time in idle (Pi), and average velocity (Va) of the base dataset.

Hong Kong Cycle [4]: After the selection of assessment measures and generation of microtrips, Hong Kong cycle first randomly selects microtrips to form a driving cycle whose length is between 10 and 30 min. After the candidate cycle is established, the assessment measures are calculated and compared with the target statistics which are calculated from the base dataset. If each of the assessment measure is different from the target mean values by less than 5%, then that cycle is accepted. Otherwise, another pre-defined number of microtrips are sampled and this process is repeated until all assessment measures are different from the target mean values by less than 5%.

11 Chinese Cities Cycles [6]: After the selection of assessment measures and generation of microtrips, 11 Chinese cities cycles first select several microtrips randomly and combine them as a candidate cycle whose length is between 900–1200 second of driving time. After the candidate cycle is established, the 11 assessment measures are calculated and compared with the target statistics which are calculated from the base dataset. If all the assessment measures are different from the target values by less than or equal to 5%, then that cycle is accepted as the candidate target driving cycle. This process is repeated until a predefined maximum repeating time is reached. Finally, the candidate driving cycle with the least-sum of absolute differences of the 11 measures is selected from all candidate driving cycles as the final target driving cycle.

Beijing Cycles [7]: After the selection of assessment measures and generation of microtrips, Beijing cycles first calculate accumulative relative differences of all measures (activity measures and emission measures) as a combo-difference (*ComboDiff*) for all generated microtrips. Then, the microtrips with the lowest *ComboDiff* are selected as candidates to be put into a microtrip pool. The size of this microtrip pool is made 130% of the numbers of microtrips that are necessary to form a driving cycle. This step, similar to the step of the comparison of all microtrips in the Pune cycle, is to reduce the number of microtrips available to form a target driving cycle. After that, 100 candidate driving cycles are randomly selected from the developed microtrips pool. To screen a final driving cycle from these 100 candidate driving cycles, a VSP based evaluation approach is used to compare the VSP distribution of the candidate driving cycle with that of the base dataset. The Mean Root Square Error (MRSE) of the VSP distribution is used to estimate the difference between two VSP distributions. The driving cycle with the least MRSE is selected as the final driving cycle.

3. Summary of Literature Review

From the discussion of existing methodologies and practices in the preceding section, the following summaries are provided for the existing research efforts:

1) Microtrip-based development method is predominantly used in the existing development of driving cycles. The common procedures in the development of driving cycles include data collection, generation of microtrips, selection of assessment measures, and development of driving cycles. Among these steps, the selection of assessment measures and the development method determine the quality of final driving cycles. Existing methodologies and practices vary for the use of assessment measures and the development method.

2) The assessment measures adopted in the existing methodologies and practices include activity measures (e.g., acceleration/deceleration and/or portion of driving mode (acceleration, deceleration, cruise, and idling) related parameters) and emission measures.

In the development of driving cycles, a set of microtrips are randomly and repeatedly selected from all generated or a portion of generated microtrips by existing methods to form a number of candidate driving cycles first. Then, the candidate driving cycle with the least values of assessment measures is usually selected as the final cycle. A maximum number of repeating times or predefined desired error is used to control the time consumed in the selection process.

3) Most of existing methodologies and practices do not include an evaluation process of developed driving cycles. Beijing driving cycles apply a VSP based evaluation approach, which implicitly accept VSP as a kind of assessment measures. This is the first research effort that incorporated the concept of VSP into the development of driving cycles.

4) All existing driving cycles have been developed under the framework of MOBILE6.2 which is an emission factor based modeling approach and for evaluating all pollutants at the same time.

In terms of the current methodology for developing driving cycles, the following five limitations are found:

1) The most of existing performance (assessment) measures do not include VSP distribution related activity information, which is widely accepted as a better descriptor of vehicle emissions.

2) The performance (assessment) measures in selecting the final driving cycle by a random manner do not guarantee to result in the minimum (optimum) performance. This limitation is caused by the random selection method by which only a small portion of possible combinations of microtrips are examined. It is thus questionable whether the final driving cycle by the random selection is the best one in a global perspective.

3) The process in the development of driving cycle is costly and inefficient. This is also due to the characterization of random based selection method. The enumeration of even a small portion of all possible driving cycles is a very time-consuming process.

4) The developed driving cycle is either not or unscientifically evaluated with respect to whether it represents real-world driving behaviors and/or traffic conditions. Existing methodology lacks a scientific MOE to evaluate the efficiency of developed driving cycles in representing real-world traffic conditions. The reason of this limitation is that, in the past, it is not clear which driving activity parameter is the best descriptor in the explanation of mobile emissions.

5) The performance of the final driving cycle is not evaluated in term of its capability in predicating real-world emissions. This is mainly due to the unavailability of the real-world emission data.

4. Conclusions

The study in this paper reviews existing methodologies for development of driving cycles for emission estimation. The common procedures in existing methodologies are synthesized. A presentation of the limitations of current methodologies and practices are provided for future research.

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