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Customizing driving cycles to support vehicle purchase and use decisions: Fuel economy estimation for alternative fuel vehicle users ☆

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ABSTRACT

Wider deployment of alternative fuel vehicles (AFVs) can help with increasing energy security and transitioning to clean vehicles. Ideally, adopters of AFVs are able to maintain the same level of mobility as users of conventional vehicles while reducing energy use and emissions. Greater knowledge of AFV benefits can support consumers' vehicle purchase and use choices. The Environmental Protection Agency's fuel economy ratings are a key source of potential benefits of using AFVs. However, the ratings are based on pre-designed and fixed driving cycles applied in laboratory conditions, neglecting the attributes of drivers and vehicle types. While the EPA ratings using pre-designed and fixed driving cycles may be unbiased they are not necessarily precise, owning to large variations in real-life driving. Thus, to better predict fuel economy for individual consumers targeting specific types of vehicles, it is important to find driving cycles that can better represent consumers' real-world driving practices instead of using pre-designed standard driving cycles. This paper presents a methodology for customizing driving cycles to provide convincing fuel economy predictions that are based on drivers' characteristics and contemporary real-world driving, along with validation efforts. The methodology takes into account current micro-driving practices in terms of maintaining speed, acceleration, braking, idling, etc., on trips. Specifically, using a large-scale driving data collected by in-vehicle Global Positioning System as part of a travel survey, a micro-trips (building block) library for California drivers is created using 54 million seconds of vehicle trajectories on more than 60,000 trips, made by 3000 drivers. To generate customized driving cycles, a new tool, known as Case Based System for Driving Cycle Design, is developed. These customized cycles can predict fuel economy more precisely for conventional vehicles vis-à-vis AFVs. This is based on a consumer's similarity in terms of their own and geographical characteristics, with a sample of micro-trips from the case library. The AFV driving cycles, created from real-world driving data, show significant differences from conventional driving cycles currently in use. This further highlights the need to enhance current fuel economy estimations by using customized driving cycles, helping consumers make more informed vehicle purchase and use decisions.

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1. Introduction

An alternative fuel vehicle (AFV) is a vehicle that runs on a fuel (e.g., battery electric) other than conventional petroleum fuels (gasoline or diesel) and also refers to any technology of powering an engine that does not involve solely petroleum (e.g., hybrid electric) (Wikipedia, 2014). Options for AFVs in market are vast but their penetration in fleets is still small, compared with conventional vehicles consuming gasoline or diesel. Enhanced energy security and cleaner travel are the major benefits that attract potential customers to transition from conventional vehicles to AFVs (Bunch et al., 1993; Nesbitt and Sperling, 1998; Struben and Sterman, 2008; Liu et al., 2015b). One of the most important aspects of vehicle purchase and use decisions concerns fuel economy.

Currently, the fuel economy is predicted by U.S. Environmental Protection Agency (EPA) using pre-designed standard driving cycles in a lab controlled condition. The precision of fuel economy estimation heavily relies on whether the driving cycle can represent real-life driving practices. EPA has designed various driving cycles, such as FTP (Federal Test Procedure, often called EPA75), HWFET (Highway Fuel Economy Driving Schedule), SFTP (Supplemental Federal Test Procedure), US06 (representing aggressive driving on highway), SC03 (representing hot ambient when AC is on) and C-FTP (representing city driving conditions in cold ambient temperature) (Davis et al., 2009; Berry, 2010), to account for various travel needs and driving contexts.

A study by Lin and Greene has shown that precision of fuel economy for individual drivers rather than bias may have limited the usefulness of EPA fuel economy ratings (Lin and Greene, 2011). To overcome the accuracy/precision issue, this study proposes the use of data from sensor/positioning technology and behavioral surveys. The question is: can a limited number of driving cycles represent trillions of vehicle trips in real-world, especially for real-world driving of AFVs? If driving practices in real-world are not similar across different vehicle groups (i.e., conventional vehicles vis-à-vis AFVs), then the answer would lean toward a "no".

The use of standard driving cycles in a lab controlled condition to test all vehicles has its own drawback. One issue is that the standard test is based on deterministic driving cycles-it basically assumes all driving activities to be similar irrespective of drivers' individual characteristics. But in real-world traffic condition, vehicles could be driven differently depending on individual's driving styles. Another issue is that the current driving cycles do not consider the use of advanced driving aid technologies, e.g., cruise control. While in reality, a greater portion of drivers has applied these technologies to ease them from driving tasks. Moreover, there is substantial uncertainty about whether AFV users drive differently given AFVs having different engine performance, which can impact their fuel economy. How to design customized driving cycles in an appropriate manner, overcoming the lack of precision when using deterministic driving cycle, is thus of interest. The customized driving cycles for transition to AFVs should be able to: (1) represent real-world driving practices based on consumers' individual characteristics; and (2) compare the fuel economy for consumers when they are driving AFVs versus conventional vehicles.

Previously, limited availability of data restrained the diversity and customization of driving cycles. Using "one-fit-all" pre-designed driving cycles was a good option. However, with increasing amounts of data generated by electronic sensors from various sources that include travelers, vehicles, infrastructure and the environment, referred to as "Big Data", customizing driving cycles for individuals using gasoline vehicles or AFVs has become feasible. Using large-scale trajectory data merged with travel behavior information, this study aims to construct a practical methodology to customize driving cycles based on real-world driving data for various users and vehicles using different power systems. These customized driving cycles can be used to better estimate fuel economy for consumers based on their own driving style instead of using a "one-fit-all" pre-designed driving cycle. A more precise fuel economy estimate can potentially help consumers choose a more energy-efficient and cleaner vehicle. This study suggests a methodology that can help move government agencies (Environmental Protection Agency) and industry (vehicle manufacturers and energy related companies) toward driving cycles that are customized and based on local or regional conditions. The scope of this study is limited to developing an alternative way of generating individualized driving cycles using a large-scale real-world driving database. This should be a step toward estimating fuel economy, but how to estimate fuel economy using driving cycles is not within the scope of this paper.

2. Literature review

The US EPA uses 5 standard test cycles based on dynamometers in laboratory conditions to provide point estimates of vehicle fuel economy to consumers. This information is valuable in making vehicle purchase and use decisions. Other than capital costs, energy costs are heavily weighted when consumers make vehicle purchase decisions (Turrentine and Kurani, 2007; Greene, 2010; Lin and Greene, 2011). Driving cycles specified by DDS (Dynamometer Drive Schedule) are often used to estimate vehicle fuel economy which is highly associated with energy costs. Delucchi et al. compared the costs, including initial vehicle cost, operating and maintenance costs, and battery replacement costs, of Battery-powered Electric Vehicles (BEVs) with conventional vehicles (CVs) consuming gasoline (Delucchi and Lipman, 2001). They calculated vehicle energy use (a big component of operating costs) over a specified driving cycle – Federal Urban Drive Schedule (FUDS) which is used in conjunction with other driving cycles by the EPA. They reported that though BEVs have advantages in energy security and environment protection, the manufacturing cost for batteries must be lowered enough, in order for BEVs to be