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Comparing real-world fuel consumption for diesel- and hydrogen-fueled transit buses and implication for emissions

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Abstract

This paper explores the influence of key factors such as speed, acceleration, and road grade on fuel consumption for diesel and hydrogen fuel cell buses under real-world operating conditions. A Vehicle Specific Power-based approach is used for modeling fuel consumption for both types of buses. To evaluate the robustness of the modeling approach, Vehicle Specific Power-based modal average fuel consumption rates are compared for diesel buses in the US and Portugal, and for the Portuguese diesel and hydrogen fuel cell buses that operate on the same route. For diesel buses there is similar intra-vehicle variability in fuel consumption using Vehicle Specific Power modes. For the fuel cell bus, the hydrogen fuel consumption rate was found to be less sensitive to Vehicle Specific Power variations and had smaller variability compared to diesel buses. Relative errors between trip fuel consumption estimates and actual fuel use, based upon predictions for a portion of real-world activity data that were not used to calibrate the models, were generally under 10% for all observations. The Vehicle Specific Power-based modeling approach is recommended for further applications as additional data become available. Emission changes based upon substituting hydrogen versus diesel buses are evaluated.

Keywords: Fuel consumption; Diesel buses; Hydrogen fuel cells; Vehicle Specific Power

1. Introduction and background

There is growing interest in the use of alternative fuels and propulsion systems for highway vehicles. Among highway vehicles, transit buses have been a focal point for development of zero- and near-zero-emissions fuel

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cell technology (Eudy and Parish, 2001). Thus, there is a need to characterize baseline fuel use of conventional diesel transit buses and to develop a consistent methodology that can be used to compare buses of various fuel types and propulsion systems.

Bus fuel consumption and efficiency are highly dependent on vehicle and engine attributes. Passenger load, travel speed, the number of stops, road grade and the frequency of traffic interruptions affect fuel consumption (Ang and Fwa, 1989). Quantitative exploration of the effects of these factors on fuel consumption is needed to develop methods and strategies for fuel consumption prediction and fuel economy improvement.

Two general approaches are usually considered in modeling fuel consumption and emissions: physically based analytical models and empirically based models. Examples of physically based modeling approaches applicable to transit buses include EcoGest and the Physical Emissions Rate Estimator (PERE). The main inputs of EcoGest include vehicle characteristics, number of passengers, roadway characteristics and a synthetic speed profile. EcoGest is capable of estimating instantaneous as well as trip average fuel consumption and emissions (Silva et al., 2006). PERE uses vehicle parameters and second-by-second driving traces as input, and estimates second-by-second fuel consumption rates (Nam and Giannelli, 2005). PERE is based upon the assumption that fuel consumption rates for diesel and gasoline vehicles, such as passenger cars and diesel buses, are determined by vehicle specific power (VSP), engine speed, engine displacement volume, vehicle mass, and other factors.

The empirically based modal approach is exemplified by the MOVES2004 model released by the US Environmental Protection Agency (EPA). MOVES2004 can estimate energy consumption for transit buses (Environmental Protection Agency, 2005). Power demand is a key variable that explains fuel consumption and emission rates (Jimenez-Palacios, 1999). VSP, a surrogate for power demand, has been used for emissions estimation for light-duty gasoline vehicles and diesel transit buses (Frey et al., 2002; Zhai et al., 2006). MOVES2004 and PERE are complementary models. Where possible, MOVES2004 is based on second-by-second measurements of vehicle fuel use and emissions obtained either using dynamometers in a laboratory or from real-world measurements from Portable Emissions Measurement Systems (PEMS). Where such data are not available, PERE may be used to fill data gaps in MOVES2004 energy consumption rates.

An example of the use of PEMS data was a study conducted by EPA, where city transit buses operated by the Ann Arbor Transit Authority (AATA) were monitored. Both fuel consumption and emission measurements were taken while buses were driven on their established routes (Environmental Protection Agency, 2002).

Hydrogen fuel cell buses have been proposed as an environmentally friendly alternative to conventional buses, since they have the potential for eliminating tailpipe emissions (Vandenborre and Sierens, 1996). The Clean Urban Transport for Europe (CUTE) Project encompassed the implementation and evaluation of both a hydrogen fuel infrastructure and fuel cell vehicles in nine participating European cities (Haraldsson et al., 2005). While life cycle-based evaluation models of hydrogen-fueled vehicles, such as the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, have been reported (Wang, 2001), few studies regarding fuel consumption and emissions reductions under real-world traffic conditions have been carried out.

2. Objectives

The principal objectives are to: evaluate factors that significantly affect transit bus fuel consumption under real-world operating conditions; develop a conceptual approach for modeling vehicle specific fuel consumption at a micro-scale taking into account key operational factors; assess differences in fuel consumption for diesel buses in the US and Portugal to evaluate the transferability of the modeling approach; compare fuel consumption for diesel and hydrogen fuel cell buses that operate on identical routes; and estimate emission changes from substitution of hydrogen-fueled buses for diesel buses.

3. Database and description

The bus databases uses data provided to the research team by EPA that were collected in cooperation with the Ann Arbor Transportation Authority (AATA) for 12 diesel transit buses and data collected in the city of