Transportation Research Part D 14 (2009) 533–540

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

A web-based support system for estimating and visualizing the emissions of diesel transit buses

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ARTICLE INFO

Keywords:
Vehicle emissions
Support system
Vehicle specific power
GPS data

ABSTRACT

Diesel transit buses are heavy-duty vehicles that are major sources of greenhouse gases and toxic pollutants. Although various models have been used to estimate their emissions, it has been difficult to effectively apply these estimation models due to the need for user-friendly interfaces, the large amounts of underlying data, and the potential data inaccuracy. In this paper, we present a web-based support system developed for transit operators who need to estimate and visualize the emissions of diesel transit buses where a micro-scale Vehicle Specific Power approach is used to estimate emissions based on global positioning system data. Case studies show that the web-based support system provides a user-friendly environment that makes it easier to apply emission estimation methodologies and visualize emissions.

1. Introduction

The US Environmental Protection Agency (EPA) (2004) lists 188 toxic air pollutants that are known or suspected to cause cancer or other serious health effects. These air pollutants include nitrogen oxides (NO_x), carbon monoxide (CO), and particulate matters (PM). The EPA estimates that sources of air toxins from mobile vehicles account for at least half of all cases of cancer. Mobile vehicles also contribute to climate change by burning fuels and releasing carbon dioxide (CO_2) into the atmosphere.

Only a small percentage of vehicles are heavy-duty diesels they produce 75% of particulate matter and 45% of nitrogen oxides (Elkins et al., 2003). As transit vehicles account for about a third of the heavy vehicle population, they are a major source of toxic pollutants and greenhouse gases. Although transit agencies have increased the use of buses powered by compressed natural gas, bio-diesel, and diesel-hybrid systems, approximately 80.3% of transit buses in 2006 were still conventional diesel (American Public Transportation Associates, 2007). They are widely because of their fuel economy and low capital costs.

The conventional methodology to determine emission rates through the use of laboratory dynamometer tests. However, some studies (Frey et al., 2002) have shown that instantaneous speed and acceleration also contribute to a vehicle's emissions. Zhai et al. (2008), for example, looked at diesel transit buses emissions using micro-scale data embracing vehicle speed, acceleration, and road slope.

The GPS-based transit automatic vehicle location (AVL) system provides a tool for estimating emissions. GPS data are collected from transit buses on a second-by-second basis. However, there is a gap between the development of emission estimation methodologies and their application to transit buses. First, the speed and location data collected by the GPS may be inaccurate due to noise and irregular geometry, and the AVL data polled at transit centers may not provide sufficient

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doi:10.1016/j.trd.2009.07.009

resolution to give a reasonable estimation. Moreover, this data may have to be used with the other types of data, thus being less than straightforward when it comes to making estimations based on daily GPS data. Additionally, to ensure that emission estimation techniques are effectively used, graphical user interfaces need to be provided for transit agencies so that they can visualize the emissions data.

The development of a computer-based tool may be useful when applying emission estimation methodologies. We develop a prototype web support system for estimating and visualizing bus emissions. Although some geographical information systems (GISs) using decision support have been used to estimate and manage air quality (Jensen et al., 2001; Elbir, 2004), there is no such support system available for estimating and visualizing the emissions of diesel transit buses.

2. Methodologies

The chassis dynamometer is a conventional approach that measures vehicle emissions by simulating driving cycles. However, this laboratory-based testing approach may not represent real-world driving and traffic conditions because transient speed and acceleration are closely related to the vehicle emissions. Tunnel studies, remote sensing and real-time measurements of a chase vehicle have also been used to measure the emissions of transit buses (Shorter et al., 2005). Nevertheless, tunnel studies and remote sensing cannot continuously measure emissions along a route.

The portable emission monitoring system (PEMS), a recently developed on-board emissions measurement device, provides an alternative measurement technique. The PEMS is capable of producing micro-scale data and representing real-world vehicle and traffic conditions. Zhai et al. (2008) used the PEMS with GPS to record vehicle emissions, speed, latitude, longitude, and altitude. They use a vehicle specific power (VSP) model to estimate modal emission rates and link average emission rates for diesel transit buses.

The VSP is defined as the power per unit mass of the source and is a convenient way to estimate a vehicle's emissions. Vehicle acceleration, road grade, tire rolling resistance and aerodynamic drag contribute to the absolute power (Koupal et al. 2002). The VSP has previously been used to estimate vehicle emissions (Jimenez-Palacios, 1999) and is a part of the MOtor Vehicle Emission Simulator (MOVES). Frey et al. and Zhai et al. applied the VSP to estimate the emissions of light-duty vehicles and transit buses.

Let VSP be the Vehicle Specific Power (kW/ton), while v be the bus speed (m/s), a be the vehicle's acceleration or deceleration (m/s^2), and $\varnothing$ be the road grade. Zhai et al. used the following when calculating the Vehicle Specific Power:

$$\mathrm{VSP} = v \times (a + 9.81 \times \sin(\varnothing) + 0.092) + 0.00021 \times v^3$$

Table 1 presents the average modal emission rates for diesel buses based on VSP bins. After the VSP value is calculated, the VSP mode is determined by the VSP range. The corresponding modal emission rates for CO_2, CO, NO_x and HC are then obtained.

3. Web-based support system

The prototype of a web-based support system is built upon wireless vehicle-to-infrastructure communication technology that periodically collects bus AVL data. The web-based support system consists of three basic components: a user-interface subsystem, a database subsystem, and an emissions estimation subsystem. The architecture of the web-based support system is presented in Fig. 1, where the arrows represent the flow of information.

3.1. Database subsystem

Data management is an important issue for transit agencies. GPS data is often transmitted to a central database server via a vehicle-to-infrastructure communication system and contains the latitude, longitude, UTC time, and speed. The quantity of GPS data produced in such a setup is generally large. In addition, the GPS data is strongly related to other types of data,

Table 1
VSP modes and average modal emission rates for diesel buses.

VSP range	VSP mode	Average modal emission rates			
		CO_2 (g/s)	CO (g/s)	NO_x (g/s)	HC (mg/s)
VSP ⩽ 0	1	2.4	0.009	0.04	1.23
0 < VSP < 2	2	7.8	0.036	0.13	1.70
2 ⩽ VSP < 4	3	12.5	0.045	0.18	1.75
4 ⩽ VSP < 6	4	17.1	0.072	0.22	1.84
6 ⩽ VSP < 8	5	21.2	0.085	0.24	1.94
8 ⩽ VSP < 10	6	24.8	0.091	0.26	2.05
10 ⩽ VSP < 13	7	27.6	0.084	0.28	2.08
VSP ⩾ 13	8	29.5	0.062	0.31	2.15

Source: Zhai et al. (2008).