



Impact of horizontal geometric design of two-lane rural roads on vehicle CO₂ emissions

David Llopis-Castelló*, Ana María Pérez-Zuriaga,
Francisco Javier Camacho-Torregrosa, Alfredo García

Highway Engineering Research Group (HERG), Universitat Politècnica de València, Camino de Vera, s/n, 46022 Valencia, Spain

ARTICLE INFO

Keywords:

Highway geometric design
CO₂ emission
Two-lane rural road
Traffic operation
Environmentally-friendly transport
Naturalistic data

ABSTRACT

In 2014, highway vehicles accounted for 72.8% of all Greenhouse Gases emissions from transportation in Europe. In the United States (US), emissions follow a similar trend. Although many initiatives try to mitigate emissions by focusing on traffic operations, little is known about the relationship between emissions and road design. It is feasible that some designs may increase average flow speed and reduce accelerations, consequently minimizing emissions.

This study aims to evaluate the impact of road horizontal alignment on CO₂ emissions produced by passenger cars using a new methodology based on naturalistic data collection. Individual continuous speed profiles were collected from actual drivers along eleven two-lane rural road sections that were divided into 29 homogeneous road segments. The CO₂ emission rate for each homogeneous road segment was estimated as the average of CO₂ emission rates of all vehicles driving, estimated by applying the VT-Micro model.

The analysis concluded that CO₂ emission rates increase with the Curvature Change Rate. Smooth road segments normally allowed drivers to reach higher speeds and maintain them with fewer accelerations. Additionally, smoother segments required less time to cover the same distance, so emissions per length were lower. It was also observed that low mean speeds produce high CO₂ emission rates and they increase even more on roads with high speed dispersions.

Based on this data, several regression models were calibrated for different vehicle types to estimate CO₂ emissions on a specific road segment. These results could be used to incorporate sustainability principles to highway geometric design.

1. Introduction

Carbon dioxide (CO₂) concentrations in the atmosphere have increased significantly over the past century. The 2014 concentration of CO₂ (397 ppm) was approximately 40% higher than that estimated during the mid-1800s, with an average growth of 2 ppm/year in the last ten years. Levels of methane (CH₄) and nitrous dioxide (NO₂) have also significantly increased (International Energy Agency, 2016).

The European Commission (2016) stated that in 2014, Greenhouse Gases (GHG) emissions from transportation represented approximately 23% of the total emissions in the European Union (EU). That year, highway vehicles accounted for 72.8% of all GHG transportation emissions, with about 53% of the CO₂ emissions attributed to inter-urban transportation. Road transportation was also

* Corresponding author.

E-mail addresses: dallocas@doctor.upv.es (D. Llopis-Castelló), anpezu@tra.upv.es (A.M. Pérez-Zuriaga), fracator@tra.upv.es (F.J. Camacho-Torregrosa), agarcia@tra.upv.es (A. García).

<https://doi.org/10.1016/j.trd.2017.12.020>

the largest source of nitrogen oxides (NO_x) emissions, accounting for 39% of total EU emissions, and was an important emission source (13%) of fine particulate matter less than or equal to $2.5\ \mu\text{m}$ in diameter ($\text{PM}_{2.5}$). Road transportation can also contribute significantly to the total emissions of other pollutants, such as sulfur oxides (SO_x) and carbon monoxide (CO).

In the United States, emissions from transportation increased by approximately 17% from 1990 to 2014 (US EPA, 2016). The combustion of fossil fuels to transport people and goods is the second largest source of CO_2 emissions, accounting for about 31% of total US CO_2 emissions in 2014. The largest sources were passenger cars (42.4%), medium- and heavy-duty trucks (23.1%), and light-duty trucks (17.8%). The transportation sector is also responsible for 20% of CH_4 emissions and 41% of N_2O emissions from fossil fuel combustion.

In light of this situation, both Europe and the United States have increased their policy measures to address issues concerning air pollution from transport. These policies primarily focus on road pricing and internalization, intelligent transport systems, urban mobility/smart cities, eco-driving courses, and speed limiters. These policies, however, do not include strategies aimed at reducing emission through highway geometric design choice in spite of the fact that this variable can influence vehicle fuel consumption and emissions.

Several models based on vehicle factors have been calibrated to estimate fuel consumption and vehicle emissions. These models are classified into two categories: models for emissions inventory and instantaneous emissions models (Park et al., 2016).

Models for emissions inventory consist of various emission factors which depend on vehicle motor features. An emission factor is normally retrieved from the model database based on several variables such as vehicle age, vehicle class, fuel type, engine technology, model year, facility type, average speed, and pollutant type. The emission factor is multiplied by the traffic activity expressed in kilometers to calculate emissions. All current models use average trip speed as the key input variable, except for the Handbook of Emission Factors for Road Transport (HBEFA) model and the Motor Vehicle Emission Simulator (MOVES) model. The HBEFA model is based on traffic situation, whereas the MOVES model is based on speed and power demand derived from driving patterns and circumstances.

Alternatively, instantaneous emissions models are generally applied in project-level or individual vehicle-level analysis, since they provide more precise spatial and temporal analyses. One example is the VT-Micro model developed by Ahn et al. (2002), a nonlinear regression model which uses a multi-dimensional polynomial model structure to predict vehicle fuel consumption and emissions, using instantaneous speed (km/h) and acceleration (km/h/s) as explanatory variables for light duty vehicles and trucks. The VT-Micro model predicts fuel consumption and emissions with a small margin of error with respect to field data (Rakha et al., 2004). However, some limitations need to be considered when applying this model: (1) the model estimates vehicle emissions for hot stabilized conditions and does not consider the vehicle warm-up effect, and (2) the model is confined to speed and acceleration levels within the data range (speed lower than 121 km/h, and acceleration between -1.5 and $3.7\ \text{m/s}^2$). Additionally, this model classifies vehicles into categories according to their emission characteristics (Rakha et al., 2004): five light duty vehicle levels (LDV) and LDV high emitters, and two light duty truck levels (LDT) and LDT high emitters.

El-Shawarby et al. (2005) validated the model and evaluated the impact of vehicle cruising speed and acceleration levels on vehicle fuel consumption and emission rates from field data. They demonstrated that vehicle fuel consumption rates per distance were the lowest in the range between 60 and 90 km/h. Vehicle cruising speeds outside this range resulted in considerable increases in fuel consumption and emission rates.

The analysis of vehicle acceleration showed that if fuel consumption and emission rates are considered only for acceleration maneuvers, emissions decrease. This is caused by the reduction in the distance and time that are required to execute the acceleration maneuver. However, the results demonstrate that if the emissions data are collected over a sufficiently long distance, the conclusions are reversed (as the level of acceleration increases, the emissions increase).

Although most studies are focused on operational variables, there are some studies that have analyzed the influence of design geometric features on fuel consumption and emission rates. The most studied geometric variable is the longitudinal grade. Boriboonsomsin and Barth (2009) studied the fuel consumption from a vehicle driving along uphill, downhill, and flat routes. The speed was held constant at 60 mph (90 km/h) to control the speed and acceleration variables across all routes. Results showed a parabolic relationship between fuel consumption and longitudinal grade (R^2 of 0.93), meaning that longitudinal grade had a significant effect on the fuel economy of light-duty vehicles. In fact, the vehicle fuel economy of the flat route was approximately 15–20% higher than for the uphill and downhill routes.

Other studies have used the estimation of speeds and accelerations as inputs for emission rate modelling because field data collection can be expensive and difficult to implement. Park and Rakha (2006) used the INTEGRATION microscopic traffic simulation software with three types of traffic control scenarios. This software estimates speeds and accelerations and uses the VT-micro framework to calculate fuel consumption and emission rates. They concluded that longitudinal grade is an important factor in fuel consumption and emissions. For a 1% increase in longitudinal grade, fuel consumption and emission rates increase approximately 9%.

Ko et al. (2013) used the truck dynamic model and non-uniform acceleration/deceleration models for creating second-by-second vehicle speed profiles based on three key factors: grades, initial speeds and critical length of grades. Simulated trips covered longitudinal grades from 0% to 9% (increased by 1%) and initial speed from 10 km/h to 110 km/h (increased by 10 km/h). These estimated speed profiles were the input to estimate fuel consumption and emissions with the MOVES model. The analysis of the outputs showed that faster initial speeds in the longitudinal grade design would reduce fuel consumption and emissions. They also concluded that fuel consumption and emissions on a segment with an upgrade of 9% were four times higher than on a flat segment.

Likewise, the research team also analyzed the design of vertical crest curves (Ko et al., 2012). Second-by-second operating speed profiles were created based on a model with the rate of vertical curvature (K) as an explanatory variable and a polynomial model for

Download English Version:

<https://daneshyari.com/en/article/7499042>

Download Persian Version:

<https://daneshyari.com/article/7499042>

[Daneshyari.com](https://daneshyari.com)