Transportation Research Part D 36 (2015) 86–95

Contents lists available at ScienceDirect

Transportation Research Part D

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

Economic-environmental analysis of traffic-calming devices

Aron Jazcilevich [a,*], José María Mares Vázquez [a], Pablo López Ramírez [b], Irma Rosas Pérez [a]

[a] *Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, Mexico*
[b] *Centro de Investigación en Geografía y Geomática, Consejo Nacional de Ciencia y Tecnología, Mexico*

ARTICLE INFO

Article history:
Available online 13 March 2015

Keywords:
Emissions
Traffic
Bumps

ABSTRACT

A set of indicators are proposed to determine the effect of traffic-calming devices on the environment and economy. They are based on vehicular emissions and energy consumption and are used to evaluate the viability and positioning of traffic-calming devices. First, a time window is defined on which the influence of a traffic-calming device can be determined providing a convenient frame of reference. Second, a concept of local cruising conditions is defined in order to have a basis of comparison between cases "with" and "without" traffic calming devices. The emissions considered were: HC, NOx, CO, PM_{10}, and CO_2. From the latter fuel consumption was estimated. Valuation of speed bumps on a secondary road in Mexico City was obtained as an example application of the proposed methodology.

Introduction

Emissions and energy costs due to vehicular travel have significant effects on the economy, environment, and urban planning. In this context the role of traffic-calming devices such as speed cushions, bumps, humps, and stop signs, has been questioned: Is there a conflict between the environment and traffic safety prevention? This discussion includes urban centers in developed and underdeveloped countries (Höglund and Niittymäki, 1999; Madjadoumbaye et al., 2012; Lee et al., 2013; Daham et al., 2005; Bellefleur, 2012).

Despite the importance of this problem, there is no consensus on the effects of these devices in terms of vehicle emissions. According to experiments by Daham et al. (2005), traffic-calming devices increased CO, NOx, and CO_2 emissions by 117%, 195%, and 90%, respectively, whereas Höglund and Niittymäki (1999) found that the increase in CO emissions ranged from 391% to 1551% and that the increase in NOx emissions ranged from −4% to +139%. Comparison studies by Daham et al. (2005) with comprehensive studies performed by Bellefleur and Gagnon (2011), show large discrepancies in the emission depending on the contaminant. Table 14, p. 44 in this reference shows that emission CO increases due to calming devices were between 7% to 71%, CO_2 increased between 7% to 19%, while reductions in NOx ranged from −60% to −38%. The disparity of these results may arise due to the different methodologies used in each study: emissions are dependent not only on vehicle kinetics and the technology but also on the cycle chosen and driver behavior during the experiment. This situation makes it difficult to achieve repeatable conditions.

This study proposes measurable and repeatable indicators to determine the effect of traffic-calming devices on the environment, energy consumption, and economy. Arguments are thus provided for an objective discussion to determine the effects of traffic calming devices with greater certainty. Our indicators are based on "real life" driving conditions that can

---

* Corresponding author.
E-mail address: jazcilev@unam.mx (A. Jazcilevich).

http://dx.doi.org/10.1016/j.trd.2015.02.010
1361-9209/© 2015 Elsevier Ltd. All rights reserved.

be used to evaluate the viability and positioning of traffic-calming devices. First a time window is defined in which the influence of a traffic-calming device can be determined, providing a convenient frame of reference for energy and emission considerations. Second, the concept of local cruising conditions is defined in order to have a basis of comparison between cases "with" and "without" traffic calming devices. The following emissions were considered: HC, NOx, CO, PM_{10}, and CO_2. The latter is used to obtain the fuel consumption rate via stoichiometry, from which energy-economic indicators can be obtained.

Using our methodology in conjunction with local data on vehicle flow and activity, the monetary costs and emissions of a specific traffic-calming device in Mexico City are determined. The proposed indicators lead to important conclusions upon which recommendations are made.

Material and methods

A set of definitions of quantifiable indicators is presented which will be used to environmentally and economically evaluate traffic-calming devices. All of this material was made operational in MATLAB® programs. First we analyze a typical speed vs. time profile due solely to the presence of a traffic-calming device and not due to interactions with other vehicles. The distinctive characteristics of this profile are then exploited to define a time interval to determine a convenient time and space frame of reference for the proposed indicators.

Characteristic speed and time window of a traffic-calming device: direct case

The following are the phases of the characteristic speed variation induced by a traffic-calming device: (a) a maximum approach speed that monotonically decreases and leads to (b) a minimum speed followed by (c) a recovery phase with positive acceleration until a new maximum speed is reached. These phases are shown in Fig. 1. The time window t_w is the time it takes for these phases to occur. This situation is characteristic when speed changes are due to the presence of a traffic-calming device and not due to interactions with other vehicles. It takes place during light traffic conditions and no queue is formed behind the calming device.

To obtain Fig. 1, a total of 49 passes were made through traffic-calming devices under light traffic conditions using different car technologies and weights. Distances and speeds were recorded every second using a global positioning system (GPS). It was observed that the range of value of t_w in seconds varies as function of vehicle's power to weight ratio: for "light" vehicles the range was (17, 29), for a modern bus (26, 30), and for underpowered vehicles (30, 48). Nevertheless, as Fig. 1 shows, the characteristic phases can be discerned. This normalized graph was obtained rescaling data of each pass by dividing the time and velocity axis by corresponding maximum values and averaging all rescaled graphs.

As shown in Fig. 1, the maximum recovery speed tends to be higher than the maximum approach speed. In addition, the absolute values of the accelerations in the recovery phase are of greater magnitude than the decelerations in the approach phase. This phenomenon can be explained through the logic used in transit models, which indicates that as distances between vehicles become larger, vehicles increase their speeds (see Treiber et al., 2000). This situation occurs immediately after passing a traffic-calming device. The phases of this direct case, which are easy to distinguish, allows for the definition of time window t_w. This will be used in the following sections.

Under light traffic conditions the change in the speed of a vehicle is due only to the presence of the traffic-calming device. Thus the profile of the characteristic phases, as shown in Fig. 1, is essentially maintained. Instances of this phenomenon can be observed in traffic data collected by other authors, as in Lee et al., 2013, Fig. 2, p. 70 where in 6 of 15 passes over calming devices the proposed characteristic phases can be recognized. This situation was not fulfilled by the other passes possibly because of interaction with traffic during the approach or recovery stage, a case not considered here.

Induced work and power for the direct case

In the following discussion row arrays will be identified by italic bold and scalars by italic non-bold letters. If the time window t_w is divided into intervals Δt_w [s], the direct induced specific work w_w, or work per unit mass [J kg^{-1}], is defined by the array dot product:

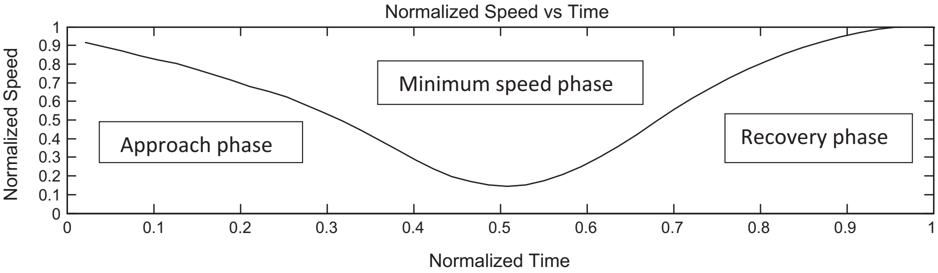

Fig. 1. Normalized time window that contains the approach, minimum, and recovery speed phases for 49 passes on a bump under light traffic conditions.