“Cumulated Vehicle Acceleration”: An Attribute of GPS Probe Vehicle Traces for On-Line Assessment of Vehicle Fuel Consumption in Traffic and Transportation Networks

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Abstract

To perform a reliable on-line assessment of fuel consumption in vehicles, we introduce “cumulated vehicle acceleration” as an attribute of GPS probe vehicle traces. The objective of the calculation of the attribute “cumulated vehicle acceleration” in the GPS probe vehicle data is to perform a reliable on-line dynamic traffic assignment for the reduction of vehicle consumption in traffic and transportation networks.

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I. INTRODUCTION

A reliable assessment of fuel consumption in vehicles is an important task of transportation engineering (see, for example [1–9] and references there). It is well-known that at a time-independent speed the speed dependence of fuel consumption in a vehicle has a minimum at speeds about 50–70 km/h. Therefore, an average speed is an usual attribute for a reliable assessment of fuel consumption in vehicles from measurements of GPS probe vehicle traces (see, for example [1–9] and references there).

However, it is also well-known that fuel consumption of a vehicle depends crucially on vehicle acceleration: Usually, at a given speed, the larger the vehicle acceleration, the larger the fuel consumption of the vehicle. There are many methods in which through the use of measurements of engine characteristics together with simulations of driver behavior, fuel consumption as a function of speed and acceleration (deceleration) has been calculated (see, for example [1–9] and references there).

Recently, based on a huge number of measurements of fuel consumption in floating car data (FCD), Koller et al. [10] have found a “pure” empirical microscopic matrix: The matrix has been derived with the use of measured data only, i.e., without any models and simulations. This empirical matrix presents microscopic empirical fuel consumption as a function of microscopic (single-vehicle) speed and acceleration (deceleration). This matrix can be used for many ITS (intelligent transportation systems) applications [11, 12].

However, due to an error in the determination of the vehicle location in GPS probe vehicle traces, it is almost impossible to determine real vehicle acceleration as a time-function with measurements of the GPS traces. Therefore, additionally to the attribute “average vehicle speed”, for an assessment of vehicle fuel consumption on a link of a traffic network researches have suggested several attributes, which should be found with the use of the GPS traces, like the number of vehicle stops on a link of a traffic network, kinetic energy of vehicles, etc.

In this paper, we introduce an attribute of GPS probe vehicle data that we call “cumulated vehicle acceleration”. “Cumulated vehicle acceleration” together with well-known attribute of GPS probe vehicle data “average vehicle speed” should allow us to perform a reliable assessment of vehicle fuel consumption on a link of a traffic network.
FIG. 1: Typical microscopic (single-vehicle) speeds (black squares) along a vehicle trajectory measured through anonymized GPS probe vehicle data of TomTom company. Dash-dotted line shows time instance of vehicle passing traffic signal; the signal location is considered the end of the city link. Data have been measured on a section of Völklinger Straße with speed limit 60 km/h (see schema of this section in Fig. 1 (a) of Ref. [13]).

II. DEFINITION OF “CUMULATED VEHICLE ACCELERATION”

In Fig. 1, we present a typical dependence of microscopic vehicle speeds determined through anonymized GPS traces of TomTom company. Features of these measured data have been discussed in detail in [13].

We define a “cumulated vehicle acceleration” $A_j$ for link $j$ of a traffic network as follows [14]:

$$A_j = \frac{1}{L_j} \sum_{n=1}^{N-1} (v_{n+1} - v_n)\theta_n,$$

(1)

where $L_j$ is the length of link $j$ of the traffic network, $v_n$ is a microscopic speed measured along vehicle trajectory on link $j$ of the traffic network at time instant $n$ (here $n = 1, 2, ..., N$, i.e., $v_1$ is the first value of a microscopic speed measured along vehicle trajectory on link $j$ of the traffic network, $v_N$ is the last value of a microscopic speed measured along vehicle trajectory on link $j$ of the traffic network, see Fig. 1),

$$\theta_n = \begin{cases} 1 & \text{if } v_{n+1} - v_n \geq \Delta v \\ 0 & \text{if } v_{n+1} - v_n < \Delta v, \end{cases}$$

(2)
Δv is a constant model parameter (Δv > 0) that is used to decrease the effect of an error in the vehicle speed \( v_n \) calculated from GPS data; for anonymized TomTom GPS data with time interval \( Δt = t_{n+1} - t_n = 5 \) s (see explanations in [13]) between measurements of the speeds one can use, for example, \( Δv = 0.5 \) [km/h].

It should be noted that the definition of “cumulated vehicle acceleration” \( A_j \) for link \( j \) of a traffic network can be applied for any link of a traffic network independent on the length of the link. Additionally, the definition of “cumulated vehicle acceleration” \( A_j \) for link \( j \) of the traffic network can be applied for any value of time interval \( Δt_n = t_{n+1} - t_n \) (where \( n = 1, 2, ..., N - 1 \)) between GPS measurements. The latter is associated with definition (1), in which the sum of speed differences between any two measurements of GPS-points is calculated.

The basic assumption made in definition (1) of “cumulated vehicle acceleration” \( A_j \) for link \( j \) of a traffic network is as follows. We assume that vehicle acceleration \( a_n \) is time-independent during time interval \( Δt_n \), i.e., it is equal to

\[
a_n = \frac{v_{n+1} - v_n}{Δt_n},
\]

where \( n = 1, 2, ..., N - 1 \).

III. DISCUSSION

Recently, Hemmerle et al. [15] and Hermanns et al. [16] have calculated a macroscopic matrix for fuel consumption on links of a traffic network. In this matrix, average fuel consumption on a link of traffic network depends on two variables: (i) “average vehicle speed” and (ii) “cumulated vehicle acceleration” as defined in this paper.

To calculate the macroscopic fuel consumption matrix, firstly, a classification of simulated traffic patterns in oversaturated city traffic has been made by Hermanns et al. [16]. For each of the traffic patterns found in microscopic traffic simulations with Kerner-Klenov stochastic three-phase traffic flow model (about 500000 patterns have been calculated) the average speed and the cumulated vehicle acceleration have been found [15, 16]. Finally, with the use of the empirical microscopic fuel consumption matrix of Koller et al. [10], Hemmerle et al. [15] have derived the macroscopic fuel consumption matrix. As mentioned, in the matrix average fuel consumption on a link of traffic network depends on the average vehicle speed.
and the cumulated vehicle acceleration.

As shown in paper by Hemmerle et al. [15], with the use of this matrix, it is possible to perform on-line dynamic traffic assignment based on actual GPS probe vehicle traces. In accordance with the methodology developed in German project UR:BAN [17, 18], the objective of such on-line dynamic traffic assignment is the reduction of vehicle consumption in city networks.

IV. CONCLUSIONS

1. “Cumulated vehicle acceleration” as defined in this paper is an useful variable for on-line assessment of vehicle fuel consumption based on measurements of GPS probe vehicle data.

2. Through the calculation of “cumulated vehicle acceleration” in measured GPS probe vehicle data, a reliable on-line dynamic traffic assignment is possible to perform. The objective of such on-line dynamic traffic assignment is the reduction of vehicle consumption in traffic and transportation networks.

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