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Assessing energy consumption impacts of traffic shifts based on real-world driving data

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ABSTRACT

Information and communication technologies used for on-board vehicle monitoring have been adopted as an additional tool to characterize mobility flows. Furthermore, traffic volumes are traditionally measured to understand cities traffic dynamics. This paper presents an innovative methodology that uses an extensive and complementary real-world dataset to make a scenario-based analysis allowing assessing energy consumption impacts of shifting traffic from peak to off-peak hours. In the specific case of the city of Lisbon, a sample of 40 drivers was monitored for a period of six months. The obtained data allowed testing the impacts of increasing the percentage of traffic shifting from peak to off-peak hours in energy consumption. Both average speed and energy consumption variations were quantified for each of the tested percentages, allowing concluding that for traffic shifts of up to 30% a positive impact in consumption can be observed. In terms of potential gains associated to shifting traffic from peak hours, reductions in energy consumption from 0.1% to 0.4% can be obtained for traffic volumes shifts from 5 to 30%. Overall, the maximum reduction in energy consumption is achieved for a 20% traffic shift. Average speed variation follows the same trend as energy consumption, but in the opposite direction, i.e. instead of decreasing, average speed increases. For the best case scenario, considering only the sections of roads with traffic sensors, a 1.4% reduction in trip time may be achieved, as well as savings of up to 6 l of fuel and 14.5 kg of avoided CO_2 emissions per day.

1. Introduction

The transportation sector is responsible for 40% of final energy consumption in Portugal, with the road transportation sector being responsible in 2013 for 81% of that energy consumption (European Commission, 2015). This is mainly due to the transportation sector dependency on fossil fuels, with inherent consequences regarding disruptions of energy supply and price volatility. Thus, there is a strong drive to reverse this trend, and the most traditional approach relies on promoting alternative vehicle technologies and energy pathways. However, focusing on a better use of the vehicle, in order to educate driver towards a more sustainable usage of the transport system, might provide additional opportunities for energy savings and avoided emissions. In this sense, information and communication technologies (ICT) can potentially be a powerful tool to promote change in the transportation sector, as already presented in previous studies (Geenhuizen, 2009; Kompfner et al., 2008). ICT applied to the transportation sector can be differentiated as fulfilling different tasks (Geenhuizen, 2009): supporting choices of vehicle drivers and/or passengers (for instance, on-

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road information or routing advice regarding traffic, driving advice to reduce fuel use); reducing options or limiting drivers' behavior (e.g. avoiding certain parts of the road network, or limiting driving speed); alerting drivers and/or passengers without restraining their behavior (e.g. several modes of advanced driver assistance); and serving to take over drivers' decisions, either fully or partly (such as electronic bonding of cars or in intelligent speed adaptation). At a more basic level ICT can be used to unobtrusively monitor driving behavior and mobility patterns, thus helping to develop and calibrate traffic, vehicle or behavioral models using real world data.

One possibility of ICT use are on-board vehicle user aid devices, which can be used, on a first stage, to characterize driving patterns and, on a second stage, to educate the driver to improve energy efficiency and reduce costs and environmental impacts associated to urban mobility. On the driving patterns characterization, several studies have used real-world driving data to find representative driving cycles (André et al., 1995; Della Ragione and Meccariello, 2017; Gonder et al., 2007; Pelkmans and Debal, 2006; Sevtsuk and Ratti, 2010; Tzirakis et al., 2006; Wang et al., 2012; Wang et al., 2008). Wang et al. (2012) used large-scale mobile phone data, with detailed Geographic Information System (GIS) data, to assess road usage patterns in urban areas. The authors found that the major usage of each road segment can be traced to its own driver sources. Based on this finding, the authors proposed a network of road usage by defining a bipartite network framework. This novel framework allowed creating a strategy that achieves a significant reduction of the travel time across the entire road system, compared to a benchmark approach. Sevtsuk and Ratti (2010) also used large-scale mobile phone data to confirm that there is significant regularity in urban mobility at different hours, days, and weeks. The authors focused on the longitudinal activity patterns of network cells rather than individual users to conclude that besides the differences between weekday and weekend travels, hourly, daily, and weekly activity distribution patterns in a city can also be significantly distinguished. Furthermore, the authors found that different hours of the day affect the activity levels of diverse areas of the city differently.

Other studies have focused on how driving patterns influence emissions and fuel consumption (Ericsson, 2001; Jensen, 1995; Smidfelt-Rosqvist, 2003; Zhang et al., 2014). Traffic research has also studied the effect of traffic planning and street design on driving patterns (Hallmark et al., 2002; Smidfelt-Rosqvist, 2003). For example, Brundell-Freij and Ericsson (2005) used a data set of over 14,000 driving patterns registered in actual traffic to assess the influence of street characteristics, driver category and vehicle performance on urban driving patterns and, consequently, on emissions and fuel consumption. Several parameters were collected namely, vehicle speed, engine speed, ambient temperature and location via GPS. The GPS information allowed assigning detailed street and traffic attributes to the driving patterns. Also information concerning the driver and the car were included in the database. With all this information the authors were able to conclude that street and traffic environment affect driving behavior in connection with driver variables (such as age and gender) and car performance. For instance, the authors found that higher density of junctions controlled by traffic lights have a decreasing effect on average speed (decreases by 16 km/h with higher density). Also the street function was found to have effects on average speed, with speed being lower on local streets than on arterials. When considering the percentage of time at acceleration levels greater than 1.5 m/s^2, which considerably impacts fuel consumption and emissions, the largest effect was found for the density of junctions controlled by traffic lights. The higher the density, the greater the percentage (4% increase) of high accelerations. This parameter was also found to be lower (1.8%) at a speed limit of 90 km/h.

Other studies have focused on the vehicle, the driver and/or the traffic environment in order to assess the relation between driving patterns and emissions and fuel consumption (André et al., 1995; Brundell-Freij and Ericsson, 2005; de Vlieger et al., 2000; Fontaras et al., 2017; Tzirakis et al., 2007). One of the few studies assessing the effect of traffic conditions on fuel consumption is the one by de Vlieger et al. (2000). The authors considered the effect of driving behavior along with traffic conditions to assess their influence on fuel consumption and emissions, concluding that traffic condition has a major effect on fuel consumption and emissions. For intense traffic conditions an increase of up to 45% on fuel consumption was observed. However, for this study a small test fleet was used and only two traffic conditions were considered (rush hours and Sundays) to conclude on the fuel consumption increase. In this sense, there is a lack of studies using extensive and complementary real-world monitoring databases to establish correlations between traffic volumes, street characteristics and vehicle dynamics. Considering this, the aim of this paper was to assess the energy consumption impacts of shifting traffic from peak hours to off-peak hours, by connecting traffic and vehicle dynamic data in an innovative approach, using an extensive real-world database for the city of Lisbon, Portugal. Such correlations allowed testing the implementation of scenarios regarding the reduction in traffic volumes during rush hours, by also assessing the impacts in energy consumption.

2. Methods and data

The methods applied and data collected for this work are described in the following sections, namely through a detailed characterization of the monitored drivers sample, of the data collection and of the performed data analysis. A generic overview of the data collected and variables considered is presented in Fig. 1.

Fig. 2 illustrates the data analysis process, explaining how the collected data was used to create profiles that were modified to account for differences in traffic volumes between hours. Full lines refer to raw data or main calculations while dashed lines refer to intermediate calculations.

2.1. Data collection

In order to obtain real-world driving data an on-board diagnostics (OBD) system connected to the vehicle OBD port was used. The tool used was the i2d (intelligence to drive) device, which is a non-intrusive system developed in an R&D project supported by the