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Influential vectors in fuel consumption by an urban bus operator: Bus route, driver behavior or vehicle type?

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ABSTRACT

Energy costs account for an important share of the total costs of urban and suburban bus operators. The purpose of this paper is to expand empirical research on bus transit operation costs and identify the key factors that influence bus energy efficiency of the overall bus fleet of one operator and aid to the management of its resources.

We estimate a set of multivariate regression models, using cross-section dataset of 488 bus drivers operating over 92 days in 2010, in 87 routes with different bus typologies, of a transit company operating in the Lisbon's Metropolitan Area (LMA), Rodoviária de Lisboa, S.A.

Our results confirm the existence of influential variables regarding energy efficiency and these are mainly: vehicle type, commercial speed, road grades over 5% and bus routes; and to a lesser extent driving events such as: sudden longitudinal decelerations and excessive engine rotation. The methodology proved to be useful for the bus operator as a decision-support tool for efficiency optimization purpose at the company level.

Introduction

The impact of the transportation sector on energy use and carbon emissions has been growing in the last decades, with this sector being responsible for more than 20% of all world energy consumption, especially those derived from petroleum (IEA, 2012). Moreover, energy costs account for an important share (more than 10%) of the total costs of urban and suburban bus operators (refer to Cubukcu, 2008, in the case of US bus transit system). Effective policies that promote the efficient use of energy, either by reducing fuel consumption or decreasing the production of greenhouses gases, are fundamental to achieving sustainability goals. According to Wen et al. (2010) these policies and their associated measures should rely on accurate estimations of fuel consumption and carbon emissions during the planning phase.

In the specific case of bus operating companies, fuel consumption represents an important share of their overall costs. An optimized use of the companies' available resources, ranging from vehicles to drivers, represents one of the main concerns of a bus operator in order to reduce fuel consumption. The improvement of the driving style of bus drivers and the implementation of rigorous maintenance practices are the main ways to achieve not only fuel cost reductions, but also mitigate environmental impacts and improve road safety. Therefore, identifying the factors that affect significantly fuel consumption in bus operation is a meaningful (and potentially powerful) management tool for these companies.

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The main purpose of this paper is to expand empirical research on bus transit operation costs and identify the key factors that influence bus energy efficiency of the overall fleet of one operator and aid to the management of its resources. In this context, we analyze the main energy efficiency vectors of a bus operator company: vehicles, drivers and routes. The methodological approach holds on the use of multivariate linear regression models to estimate fuel consumption based on activity indicators of the bus operator, associated with each of these energy vectors. We applied our methodology to the case-study of a suburban bus operator of the Lisbon Metropolitan Area, Rodoviária de Lisboa, S.A. (RL). These models can provide the operator with a tool that allows a better aggregate identification of the key aspects that affect energy efficiency of its fleet and, eventually, enable significant improvements in total energy consumption by acting on the design and operation of its bus routes and the performance of its drivers.

This paper is organized in four sections. Besides this introduction, relevant literature is reviewed in Section 'Literature review' focusing on the main factors that influence fuel consumption in bus operators, also including examples of models already developed. Section 'Methodology' presents the developed models, comprising details about data collection, calibration and validation, as well as presentation of results and discussion. Finally, some conclusions and recommendations are outlined in Section 'Results and discussion'.

Literature review

Previous studies on the energy efficiency of bus operators have focused on how the different operation aspects affect final energy consumption of fleets and how the efficiencies inferred may be said to correlate with types of vehicles, their use (i.e., driver behavior) and size of operation (i.e., types of routes they operate). The characteristics associated with each of these elements impose different levels of impact on a company's overall fuel consumption.

Many initiatives are taken on the vehicle side, for example, improving the performance of powertrains and transmission systems (namely, shifting to variable transmission), reducing the needs of ancillary devices (e.g., more efficient A/C systems), using alternative technologies both on the energy side (usually Compressed Natural Gas) and the engine side (shifting to hybrid, fuel cell, or full electric vehicles). For instance, Ang (1991) used inferential statistics from samples collected in a bus fleet to determine the effects of four technological changes on the fuel consumption of buses: (i) brand of engine oil used, (ii) switch from cross-ply to radial tires, (iii) engine overhaul, and (iv) vehicle maintenance. Results revealed statistically significant savings in most of the comparisons carried out. Bus maintenance is also relevant. Bus maintenance is also relevant, with Ang and Deng (1990) having studied the effects of maintenance on the fuel efficiency of a fleet of public buses. The research was based on regression analysis and considered maintenance as comprising all interventions on a bus, with the exception of engine overhaul, aimed at improving its roadworthiness. It was divided into three types: major, minor and ineffective, performed by the bus operator at different intervals, and according to the expected level of impact on fuel consumption. Two models were produced: one exploring a general model, the other one a reduced specification, with the collected data coming from vehicles operating under normal conditions. Results showed a significant influence on fuel economy when a major maintenance was introduced. Conversely, it did not happen with minor maintenances, found to be insignificant to this matter.

Regarding the drivers, most studies focus on improving their behavior in order to improve their energy efficiency. Training actions have proven to be effective to some extent and the International Energy Agency (IEA, 2010) has indicated that such initiatives are one important piece for overall energy efficiency improvements. For instance, the implementation of formative training and driver monitoring associated with correction and improvement of driving actions allowed Rodoviária de Lisboa to achieve a global reduction of circa 2.5% in fuel consumption from 2004 to 2007, as documented in Duarte et al. (2013) and RL (2008). However, other surveys indicate that although training actions induce significant reductions of energy consumption during the training period and in the short-term period after, these gains tend to decrease in the medium- and long-term if no additional actions are undertaken. For instance, the Centre for Renewable Energy Sources in Greece (Zarkadoula et al., 2007), conducted a six-phase eco-driving pilot study to evaluate the effects of changing bus drivers' behavior through training courses. Drivers were then able to save an average of 10.2% in fuel during the training period, while in the post-training period the overall reduction was of 4.35% much less than in training. Beusen et al. (2009) corroborate with these observations in the case of car drivers. Their fuel consumption was reduced by 5.8% after four-month training sessions but a few monitored drivers fell back into their original driving habits. Following the same pattern, an interesting result related to the influence of training in fuel consumption was also found in a study developed by af Wåhlberg (2007), where he analyzed long-term effects of training on fuel-efficient driving considering three variables: fuel consumption, accident rates and acceleration behavior. The results of the study indicated that the effects on these variables were very strong during the training, again (Johansson et al., 1999; af Wåhlberg, 2002), but were not well transferred into the drivers daily work, with the reduction on fuel consumption around 2% along a one-year period after the training. To counteract these downtrends, regular updates through information campaigns and driver training are needed in order to ensure longer-term savings. In-car feedback instruments would support this, as the IEA (2010) and Duarte et al. (2013) argue. In fact, these authors (Duarte et al., 2013) examined the strategies of modifying driver behavior adopted by two bus companies operating in the same area of our study (LMA) to minimize fuel consumption and associated emissions. One of them was the same bus operator we analyze here (Rodoviária de Lisboa, S.A.) that uses a commercial tool for monitoring buses during regular work, with data collected based on events representing undesired behavior that was subsequently used as the basis