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Applying energy approach in the evaluation of eco-driving skill and eco-driving training of truck drivers

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ABSTRACT

In spite of the vast progress in the field of eco-friendly transportation technologies, complete rejection of combustion engine powered vehicles, especially in the cargo transportation sector, is still far off. As road transportation of freight contributes significantly to global transport emissions, minimizing truck fuel consumption is an urgent matter. In this article, eco-driving skills of truck drivers are considered as an important factor in reducing fuel consumption. To allow for an objective and dynamic assessment of eco-driving skills, we used an energy approach and calculated integrated indicators, directly characterizing nonproductive energy expenditures while driving. In the first experiment, drivers of higher qualifications demonstrated better eco-driving skills. In the second experiment, 10 drivers received eco-driving training with an instructor, supported by a device measuring nonproductive energy expenditures. As a result of the training, reduction of fuel consumption by 13.6% in average was achieved. Long-term effect of the training was moderate (4% reduction in fuel consumption 3 months after the training). Promotion of eco-driving training in transportation companies could bring a significant reduction in fuel expenses and CO2 emissions. However, a long-term driver support after completion of eco-driving training is necessary to reinforce changes in the driver behavior.

1. Introduction

Reducing CO2 emissions is a critical aim of international climate policy. During the 21st Conference of Parties to the United Nations Framework Convention on Climate Change the participating countries agreed to cut carbon emissions with the goal of limiting global warming at 2 °C or less, in comparison to pre-industrialization levels. As road transport contributes significantly to the rise in global transport emissions (IEA, 2014), new fuel-saving technologies are urgent. Although there is already a volume of technologies available in the automotive industry which allow for the partial rejection of fossil fuels, widespread use of vehicles with electric motors is still far off and not a current reality. Therefore, finding new ways of reducing fuel consumption for vehicles with gasoline engines is an urgent matter.

Along with the development of new fuel-saving technologies changing driver behavior is an additional measure for minimizing fuel consumption and emissions. Ahn et al. (2002) mention driver-related factors, such as driver behavior and aggressiveness among six categories of variables, that influence fuel consumption and emissions of a vehicle. The recent research by Mudgal et al. (2014) has revealed essential differences in driver's speed profiles with significantly higher emissions during acceleration periods (the latter was linked to a higher fuel consumption). However, evidence of driver behavior's impact on fuel consumption was already documented in the 1980-s (e.g. Wasielewski et al., 1980; Siero et al., 1989).

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1.1. The concept of eco-driving

The concept of eco-driving encompasses driving strategies that ensure lowest-possible fuel consumption and emissions, taking into consideration technical state of a car and road conditions. The strategies include avoiding unnecessary idling, reducing excessive vehicle speeds, avoiding quick and unnecessary accelerations, etc. There are already several models of optimal driving strategy which should lead to the lowest-possible fuel consumption (e.g. Saboohi & Farzaneh, 2009; Saerens and Van den Bulck, 2013). The results of driver training programs (Siero et al., 1989; Zarkadoula et al., 2007; Barth and Boriboonsomsin, 2009; Beusena et al., 2009; Rutty et al., 2013) show, that fuel consumption can be lowered by 6–15%. On average, eco-driving strategies help to reduce fuel consumption by 10 percent (thereby also reducing emissions), and can be considered a climate change initiative (Barkenbus, 2010). Nevertheless, mass driver training programs often do not include teaching eco-driving skills. One possible reason for this is the need for measurement tools which would allow for the objective assessment of eco-driving skills.

Along with the term “eco-driving”, there are also another terms: “economical driving”, or “fuel-efficient driving”, which have been used interchangeably (e.g. af Wählberg, 2007). Currently, the concept of eco-driving encompasses more than just driver behavior (e.g. general maintenance of the vehicle, telematics, traffic management, computer driving assistance). In this article, we will use the term “eco-driving” which should be understood as a driving pattern ensuring least-possible fuel consumption.

Minimizing fuel consumption is important not only from the perspective of solving and preventing ecological problems, but is also a way to reduce fuel expenses. The latter is especially of an interest for large transportation companies. Moreover, these companies consume much more fuel compared to individual car owners, contributing significantly more CO2 emissions (e.g. Barth and Boriboonsomsin, 2009). The material interest of transportation companies in reducing fuel costs can be motivation for implementing eco-driving training, therefore reducing fuel consumption and emissions on a large scale. Unfortunately, transportation companies often lack measurement technologies to assess employees' eco-driving skill. Fuel consumption measurement for individual drivers is difficult to put into practice in larger companies (e.g. af Wählberg, 2007, p. 334).

Hence, there is a need to more closely examine objective methods of driving skill evaluation, which can then be applied to the evaluation and development of eco-driving skill. In this article, we provide an overview of such methods, introduce the energy approach and analyze experimental work on applying the energy approach to the evaluation of eco-driving skill and eco-driving skill training.

1.2. Approaches to the evaluation of eco-driving skill

Speed, steering angle, acceleration, curvature of driving loci, frequency of emergency braking, etc. are often singled out as the parameters that provide an objective driving quality control (Duncan et al., 1991; Kuramori et al., 2010). Based on measuring separate parameters, more generalized indicators such as Greenshields’ index G and quality movement indicator Q (Greenshields et al., 1947) can be obtained (1):

$$G = \frac{t \cdot \Delta V \cdot \Delta \theta \cdot \Delta a}{d}; \quad Q = \frac{k \cdot V}{\Delta V}\sqrt{f}, \tag{1}$$

where t – time of motion, d – length of the investigated section of the road, ΔV – total speed change, $\Delta\Theta$ – total change of direction, Δa – total change of acceleration, V – average speed, f – speed change per distance unit, k – constant.

All the factors characterizing driver's craftsmanship by fuel consumption can be divided into two groups. The first group includes factors that ensure reduction of fuel consumption by means of driver's influence on technical condition of the car, his choice of an optimal route, road and traffic conditions. This group of factors should be analyzed together with the activity of transportation service and technical service of a company and is not considered in this article. The second group of factors encompasses the craftsmanship of eco-driving based on a specific technical condition of a particular car, given road conditions and traffic conditions. In this case, the skill of eco-driving is achieved by complying with certain rules of driving during the start and warm-up of the engine, maneuvering at loading and unloading points, and, the most important, in the process of driving on the route. Currently, driving control is considered as a perspective way of minimizing fuel consumption and emissions (e.g. Rutty et al., 2013; Saerens and Van den Bulck, 2013; Mudgal et al., 2014). Adherence to the rules of eco-driving during start-up, warm-up and maneuvering can be ensured by appropriate actions of motor transport enterprises and on the points of loading and unloading. The most important and difficult to execute are the rules determining fuel saving in the process of moving on the route.

A driver has two main and fundamentally different methods in this regard. The first method is to ensure the reception of mechanical energy from the engine with least possible specific consumption of fuel, by maintaining economical speed and load operating conditions of the engine and transmission units. The second method implies using the energy received from the engine most effectively. The first method is realized by an optimal influence on control driving gears, providing the necessary speed and load modes, that is, mainly by means of driving techniques. The second method, in turn, is realized by means of an optimal accumulation of kinetic energy during acceleration and its minimal dispersion while braking, i.e., by a tactical skill of the driver, his ability to calculate and betimes reduce speed passing by traffic lights and obstacles in order to ensure minimal braking (Sivak and Schoettle, 2012; Mensing et al., 2013).

The issues of improving eco-driving skills by applying the first method have been studied well. The result of these investigations led to the specification of the limits within which an engine works most economically. As a practical application, recommendations ensuring the shift of operational modes spectrum to a more economical zone were elaborated.

In this article, we will mainly discuss the realization of the second method, i.e., reduction of unproductive energy loss while