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Technologies for transport decarbonisation: options, impacts and uncertainties

The effect of pavement type and characteristics on rolling resistance of heavy-duty trucks from a road management perspective

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In 2019, the transportation sector accounted for 25% of Canada's greenhouse gas (GHG) emissions, with a significant 54% increase between 1990 and 2019. Although GHG emissions from cars have decreased by 21% during this period, GHG emissions from freight trucks more than tripled [1].

One possible solution to reverse this current trend is the electrification of transport. The Government of Canada has decided to ban the sale of new gasoline-only cars by 2035 [2]. This incitive will, however, have a limited impact on GHG emissions in Canada, as it does not affect the road freight transport (heavy duty trucks), which in 2019 represented approximately 35% of Canada's GHG emissions for the transportation sector. This represents 6% of total emissions nationwide [1]. For this reason, it is still relevant to work on different ways to increase the fuel efficiency of trucks.

Policymakers have options other than electrification to reduce GHG emissions from the transportation sector. One of them is to adapt road management to optimize the fuel consumption of road traffic. Specifically, the type of pavement (cement vs asphalt concrete), the particular structure and material of the pavement, and resurfacing interventions can affect traffic fuel consumption [3]–[6]. This is especially true for heavy-duty trucks [7]. Although the fuel consumption of an individual truck associated with the physical properties of pavement may appear to be low, it is significant over a full pavement life because all vehicles traveling on the pavement are consistently affected [7].

One of the most important aspects for the reduction of heavy-duty trucks fuel consumption is the losses incurred due to rolling resistance. Indeed, rolling resistance consumes 50% of the power supplied by the engine for a 44-ton semi-trailer traveling at a constant speed of 90 km/h on a flat road [8].

About 80% to 95% of rolling resistance of trucks is due to viscoelastic deformation inside the tire structure [9]. This phenomenon varies depending on the tire temperature, pressure in the air chamber, aspect ratio, speed, etc [10]–[12]. The rest of rolling resistance is attributed to the physical interaction between the truck and the pavement. It can be divided into three physical phenomena. (1) Pavement roughness: this feature (road wavelengths between 0.5 and 50 m) is responsible of movements in the suspension dampers which dissipates energy that must be compensated by the engine [13], [14]. (2) Macro-texture: this feature (road wavelengths between 0.0005 and 0.050 m) creates additional viscoelastic deformations on the tire tread [15]. (3) Viscoelasticity of pavement: this feature dissipates energy inside the road structure. This is especially true for asphalt concrete pavements when the ambient temperature is above 20°C [3], [4], [16]–[20].

From the point of view of road management, the most important issue in reducing the fuel consumption of traffic is the difference between cement and asphalt concrete pavements regarding rolling resistance. Cement concrete pavements are much stiffer and more elastic than asphalt concrete pavements which exhibit a more viscoelastic behaviour. In addition, the roughness of asphalt concrete pavements increases more rapidly over time compared to cement concrete pavements. This is confirmed by the data provided by the Ministry of Transport of Quebec (Canada). For these reasons, this study focused on modeling and simulation of the effect of pavement viscoelasticity and roughness on rolling resistance of heavy-duty trucks. The results were calculated using a custom made software called MapEUR (Map Energy Use on Road), a modeling tool developed at Laval University that simulates fuel consumption and various components of a truck energy transfers [21].

Pavement roughness has been defined with a new roughness index which is more relevant to the suspension dynamics of trucks. A statistical approach was used to estimate the energy dissipated in the dampers for each possible truck load. The final objective is to estimate the fuel consumption of trucks associated with the movement of dampers for a specific road using only the new roughness index, the number of trucks traveling on that road and the probability density function of truck masses.

The contribution of the viscoelasticity of pavements to rolling resistance was estimated with results extracted from the literature [4], [5], [19] and has been normalized for a constant pavement configuration by using scaling relationships [3]. An exponential regression describing the rolling resistance force of the viscoelasticity of the asphalt concrete pavement as a function of pavement temperature has been implemented in MapEUR.

The roughness simulation carried out with a quarter-car model running on the highway profile data from the Ministry of Transport of Quebec showed that the energy dissipated in the dampers of a 53.5-ton truck is, on average, responsible for 0.4 % of the fuel consumption (assuming a total fuel consumption of 40 L/km). This represents an increase of 0.14 L/100 km. It should be noted that this value is highly variable along the route. There is a 20 % probability that the energy dissipation in the dampers contributes more than 0.5% of the fuel consumption. At the time of this writing, further investigation and analysis is needed to assess the difference between cement and asphalt concrete pavements in regards to energy dissipation in dampers.

A one-year simulation with MapEUR to quantify the viscoelastic contribution of pavement to rolling resistance was carried out with a 38-ton truck and a 50-ton truck on Highway 20 (Quebec, Canada) made up only of asphalt or cement concrete pavements. On average, the scenario with only asphalt concrete pavements consumed 0.36 L/100 km and 0.50 L/100 km more fuel than the scenario with only cement concrete pavements for the 38-ton truck and the 50-ton truck respectively. Il should be noted that the contribution to rolling resistance of pavement viscoelastic behaviour was almost negligible throughout the winter. The maximum peak value during the summer was 2.25 L/100 km and 2.6 L/100 km for the 38-ton truck and 50-ton truck respectively. Therefore, the average values mentioned above are only valid for Highway 20 in Quebec, Canada and higher values of fuel consumption difference between the two scenarios should be expected in a country where the average pavement temperature is higher.

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