Research of Factors Affecting Trucks Fuel Consumption: Review

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Abstract. One of the ways to save fuel for a road transport enterprise is to improve the regulation of consumption when using trucks in various operating conditions. In this review, domestic and foreign studies of factors affecting fuel consumption were considered. The review of studies shows that several factors are affecting the fuel consumption of vehicles in real operating conditions, which are not taken into account by the current Russian standards for the consumption of fuels and lubricants for road transport. Also, factors such as the rate of fuel consumption for freight turnover and the age of the vehicles need to be clarified. A review of studies has shown that the existing rates of fuel consumption for transport work do not meet modern requirements and additional accounting or clarification of the influence of such factors as the total mass of vehicles, the utilization rate of the carrying capacity, the age of the rolling stock and the technical speed is necessary.

1. Introduction
Fuel efficiency evaluates the properties of a vehicle by the ratio of fuel consumption to freight turnover performed. One of the ways to save fuel for a road transport enterprise is to improve the regulation of consumption when using trucks in various operating conditions. The main physical factors affecting fuel consumption are associated with mechanical losses in the engine and transmission, as well as with overcoming the resistance to movement of the car, which consists of the costs of overcoming rolling resistance, aerodynamic resistance, and inertia forces. Improving the efficiency of fuel consumption of freight transport is achieved by technical and organizational measures.

Organizational factors affecting fuel consumption are usually referred to [1]:
- load factor (or the actual mass of the vehicle with a load);
- running efficiency;
- age of vehicles;
- technical speed;
- driver qualifications.

2. Research
According to the data of Goryaev et al. [1], the main factors affecting fuel consumption for freight turnover have been analyzed: gross vehicle weight; technical speed; load factor, and age of vehicles.
The mass of a vehicle is one of the main factors affecting the fuel consumption of a vehicle [2]. With an increase in the mass of vehicles, fuel consumption increases, however, some authors consider that the increase occurs in a linear relationship, other studies [3] speak of a more complex relationship.

At work Hammarström [4] the fuel consumption of trucks was investigated in various road conditions. The study was carried out in Sweden for trucks with a GVW of 10–40 tonnes at three speeds with different inclines. Research results have shown that with a positive slope (from 0% to +4%), fuel consumption decreases with increasing vehicle speed.

Investigations of the fuel consumption of trucks with a gross weight of 11 tons carried out in Germany by Falkner W. [5] revealed the influence of technical speed on fuel consumption. The study showed that in free traffic conditions, with an increase in the technical speed of freight transport, fuel consumption increases: at a vehicle speed of 60 km / h, fuel consumption is 19.4 l/100 km, at a speed of 70 km / h - 21.4 l/100 km (+ 10.3%), at a speed of 80 km / h - 25 l / 100 km (+ 28.9%), at a speed of 90 km / h - 27.8 l / 100 km (+ 43.3%).

The load is considered one of the main factors affecting fuel consumption for transportation. Increasing the utilization rate of carrying capacity for freight transport is generally recognized as the most effective way to improve the energy efficiency of road transport [6, 7, 8].

Many authors [6, 7, 8, 9, 10, 11, 12, 20] have studied the effect of load on the fuel consumption of trucks. They investigated the relationship between energy and total vehicle weight. Increasing the carrying capacity of trucks will initially lead to lower road transport costs per tonne-kilometer. For a road vehicle, the maximum load is the difference between the gross vehicle weight and the unladen vehicle weight. The maximum permissible vehicle weight is currently 40 tons in many European countries, which gives a maximum carrying capacity of about 25 tons per one heavy vehicle [8, 9, 10]. As an example, McKinnon [10] clarified that for the UK, two historical weight limits increase from 38 tons to 40 tons (in 1999) and from 41 tons to 44 tons (in 2001), a decrease in the cost of road transport by 7% and 11, respectively, %. Due to the much higher load capacity (60 tonnes) for heavy trucks, cost savings are likely to be 20% to 30% compared to conventional 40 tonnes [13].

Coyle M. (2007) [11] investigated the effect of load on fuel consumption for a DAF 75.310PS 3-axle 2-wheel drive truck in the UK. The studies carried out revealed the relationship between fuel consumption (in l / 100tkm) and the total weight of the vehicle (in tons). The results of the study of the dependence of fuel consumption on transport work show that with a load capacity utilization rate of 0.5, fuel consumption for freight turnover is 1.23 l / 100 tonne-kilometre, and with a load factor of 1 -0.93 l / 100 tonne-kilometre. The author concludes that fuel consumption for transport work is nonlinearly dependent on the load.

In the works of Christophe and Madre [8, 12] for heavy-duty vehicles, fuel consumption was calculated depending on the type of vehicles, vehicle weight, and selected speed when using 50 and 100% of the carrying capacity. The authors of works [8, 12] considered trucks that meet the Euro4 standards, but the results are not so different for older trucks. These studies have shown that the fuel consumption of vehicles depends not only on the gross vehicle weight and the load factor, but also on the technical speed. The result is obtained: with a load capacity utilization rate of 0.5, fuel consumption is: at a speed of 20 km / h - 51.1 l / 100 km, at a speed of 60 km / h - 28.9 l / 100 km, and 25.6 l / 100 km (at a speed of 80 km / h). At the same time, the traffic conditions were combined - from mash to free.

Turkensteen [14] examines factors affecting fuel consumption such as vehicle load and selected speed. The author makes the assumption that fuel consumption is a function of the vehicle's technical speed.

The authors of [1, 15, 16] show that there are several factors affecting fuel consumption by vehicles in real operating conditions, which are not taken into account by the "Norms of consumption of fuels and lubricants for road transport" approved by the Ministry of Transport of Russia. In addition, factors such as the rate of fuel consumption for transport work and the age of the rolling stock need to be clarified.
Borisov et al. [17] considered various methods for determining fuel consumption in road transport. It is shown that the actual fuel consumption differs from the values calculated according to the Standards both upward and downward. Thus, these researchers conclude that the current methodology for rationing fuel consumption does not take into account factors that significantly affect fuel consumption, such as the category of roads and vehicle speed.

Kuzmin [15] provides an analysis of the current methodology for rationing the consumption of fuels and lubricants. According to the author, the current methodology needs significant clarification and refinement, since it does not take into account some components of the fuel balance that significantly affect the linear rate of fuel consumption, in particular, the effect of longitudinal slopes of roads on traffic routes during vehicle operation.

One of the factors affecting fuel consumption is the technical condition of the vehicle, which changes with the age of the vehicles [18]. The paper deals with the problem of increasing variable costs by increasing the age of vehicles in intercity road transport. The study was carried out in Poland and showed that the average fuel consumption increases by 1.5% every year. The author suggested that fuel consumption significantly depends on the age of the vehicles. Similar studies carried out in Russia using satellite navigation [19, 21] also revealed a linear character of the dependence for the first 10 years of operation, but the annual increase was 1%.

Also, in another work [16], the dependence of variable costs on the age of the vehicles for VOLVO FH12 truck tractors was determined and a method for taking into account the age of the vehicles when choosing a route was proposed.

3. Conclusion
A review of research shows that the existing rates of fuel consumption for transport work do not correspond to modern conditions. The main factors affecting fuel consumption are: linear fuel consumption rate, gross vehicle weight, load factor, vehicles age, and technical speed as a summing factor of driving conditions.

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