A methodology for evaluating the efficiency of driving a truck

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Abstract. The article considers the issues of evaluating the efficiency of converting thermal energy into mechanical work when operating pit vehicles - BELAZ-7540B dump trucks in mountain conditions and the role of the driving skills in this process. The article also defines the efficiency of driving a vehicle, based on which it presents a methodology and mathematical models for evaluating the driver’s efficiency. At the same time, the basis is formed by several operational indicators, out of which the most important ones for mountain operating conditions of heavy-duty trucks - dump trucks are energy, economic and reliability indicators. The driver’s efficiency is evaluated by the energy and economic indicators based on the trip fuel consumption and the performance of the vehicle - dump truck per shift. The efficiency of driving a heavy-duty truck - a dump truck by the material costs indicator is evaluated by the consumption of spare parts and repair and maintenance materials. The driver’s efficiency is evaluated by the reliability indicators based on the specific time, labor, and money costs spent on eliminating operational and resource failures.

1. Introduction
A vehicle is a kind of an energy machine. In a vehicle, thermal (as usual) energy is converted into mechanical work used to transport passengers and cargo. Unlike a passenger car, a truck typically converts more energy into mechanical work, which is used to perform a large number of useful operations. In both cases, the efficiency of the conversion of thermal energy into mechanical work used to perform some useful operations depends on a large number of parameters (criteria). Along with the design parameters and characteristics of the vehicle, an important role is given to the driver’s efficiency. The driver acts as a key factor in the formation and regulation of the efficiency of converting thermal energy into mechanical work, which is used to perform useful operations (transport operations). Consequently, the driver of a heavy-duty truck is actively involved in the conversion of much (significantly) more thermal energy into useful operations, thus forming the operating efficiency of the vehicle and the Driver-Vehicle-Road-Environment system in general.

It is one thing when the driver participates in the conversion of thermal energy into useful work in normal vehicle operating conditions, but it is absolutely different to drive a heavy-duty vehicle, or rather to manage the conversion of thermal energy to perform a large volume of useful operations according to a two-shift working schedule, in severe mountain and high-altitude conditions with a complex road geometric pattern in plan and profile with a gravel coating, with inevitably frequent and sharp maneuvers.
2. Nature of the problem
The truck driver’s efficiency can be defined as a ratio of the achieved result (in its energy, reliability, economic, environmental, and material terms) in the process of converting thermal energy into mechanical work, which is used to transport passengers and cargo involving the driver to the resources used.

The essence of the concept of the driver’s efficiency is much broader than the concept of the driver’s reliability. If the driver’s reliability is the ability to faultlessly drive a vehicle in various road and weather conditions during working hours, the efficiency is the driver’s reliability achieved with the least energy, economic and material costs, as well as with the least environmental damage, which can be generally expressed by the ratio:

$$ E_D = \frac{R_L}{R_A} $$

(1)

where $R_L$ is the result achieved by the driver during lean driving; $R_A$ is the result achieved by the driver during aggressive driving.

For a comprehensive evaluation of the driver’s efficiency $E_D$ when building hydraulic structures in mountain conditions, we use the following expression

$$ E_D = \frac{E_{en} \cdot E_{ec} \cdot E_{re} \cdot E_{m}}{g_{32}} $$

(2)

where $E_{en}$, $E_{ec}$, $E_{re}$, $E_{m}$ are, respectively, the components of the vehicle driving efficiency in terms of the energy, economic, reliability indicators, as well as in terms of material costs.

The achieved result of the truck driver’s efficiency consists of a large number of factors: energy, economic, reliability, material, environmental, and efficiency by ensuring traffic safety.

Not all of the above factors are significant for mountain and high-altitude operating conditions for trucks [1]. The achieved environmental result of the driver’s efficiency in the conditions of building hydraulic structures is negligible [2]. The fact is that these conditions are characterized by good ventilation. Pit roads are characterized by low traffic density and intensity, and the truck fleet is equipped with diesel engines [3-4].

3. Experimental study
Over the entire period of building Rogunskaya HPP, no traffic accidents with serious consequences were recorded.

Given the insignificance of the influence of the achieved results of the environmental efficiency, as well as the efficiency due to ensuring traffic safety in the above conditions, they may not be taken into account in practical calculations of evaluating the driving efficiency [5-6].

The energy component of the driver’s efficiency $E_{en}$ is mainly formed due to the specific fuel consumption per unit of the performed work or per unit of the operating time (Figure 1).

The mountain and high-altitude conditions of operating heavy-duty dump trucks are characterized by a relatively low energy efficiency of the driver, and it depends on a large number of factors, out of which the driver’s skills, knowledge, and experience of driving in difficult mountain conditions are important [7-8].

The efficiency of driving a heavy-duty truck - a dump truck by the economic indicator $E_{ec}$ can be indirectly evaluated by the performance per shift, which varies widely depending on the driving style (Figure 1). In the conditions of building Rogunskaya HPP, the best indicators of the performance per shift are observed, starting from the driver’s three-year to sixteen-year length of service, reaching the maximum value by the eighth year of the driver’s length of service.

The efficiency of driving a heavy-duty truck - a dump truck by the material costs indicator $E_{m}$ can be evaluated by the consumption of spare parts and repair and maintenance materials (Figure 2).
The economic criteria for the vehicle’s failure-free operation and durability are taken as a parameter to evaluate the efficiency of driving a heavy-duty truck - a dump truck by the reliability indicator $E_r$, in particular the specific time, labor and money costs spent on eliminating operational and resource failures (Figure 3).

The energy efficiency of driving can be determined from the ratio 

$$E_{en} = \frac{Q_{min}}{Q},$$

(3)
where $Q_{\text{min}}$ and $Q_i$ are the minimum and current values of the trip fuel consumption, respectively.

The economic efficiency of driving be determined from the ratio

$$E_{\text{ec}} = \frac{P_{\text{max}}}{P_i},$$  \hspace{1cm} (4)

where $P_{\text{max}}$ and $P_i$ are the maximum and current values of the vehicle performance per shift, respectively.

The driving efficiency by the reliability indicators is expressed by the ratio

$$E_r = \frac{R_{\text{max}}}{R_i},$$  \hspace{1cm} (5)

where $R_{\text{max}}$ and $R_i$ are the maximum and current values of the vehicle’s estimated reliability indicators, respectively.

The driving efficiency by the material costs indicator can be determined from the ratio

$$E_m = \frac{M_{\text{min}}}{M_i},$$  \hspace{1cm} (6)

where $M_{\text{min}}$ and $M_i$ are the minimum and current values of material costs, respectively.

Taking into account expressions (3 – 6), expression (2) can be rewritten as follows

$$D = \frac{Q_{\text{min}} \cdot P_{\text{max}} \cdot R_{\text{max}} \cdot M_{\text{min}}}{Q_i \cdot P_i \cdot R_i \cdot M_i}.$$  \hspace{1cm} (7)

An empirical formula in the form of the Lagrange interpolation polynomial is proposed to calculate the efficiency of driving BelAZ-7540B heavy-duty pit dump trucks used in the construction of Rogunskaya HPP [9-10]

$$E_t = 0.008857 \cdot t^3 + 0.5824 \cdot t^2 + 10.63 \cdot t + 41.31,$$  \hspace{1cm} (8)

where $t$ is the driver’s length of service, years.

### 4. Results

Based on the long-term observations, we made calculations for BelAZ-7540B heavy-duty pit dump trucks in the operating conditions when building Rogunskata HPP to evaluate the driving efficiency, using expression (7). The calculation results are given in Table 1.

| Efficiency evaluation indicator | 0     | 5     | 10    | 15    | 20    | 25    | 30    |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|
| Trip fuel consumption, Ql/(100 km) | 208   | 190   | 179.5 | 176.5 | 176.5 | 178   | 180   |
| $Q_{\text{min}} / Q_i$ | 0.8486 | 0.9289 | 0.9833 | 1.0   | 1.0   | 0.9916 | 0.9806 |
| Performance per shift, P, t/cm | 315   | 353   | 354   | 350   | 343   | 333   | 320   |
| $P_{\text{max}} / P_i$ | 0.8873 | 0.9994 | 0.9972 | 0.9859 | 0.9662 | 0.9380 | 0.9014 |
| Material costs, Ml | 95.0  | 80.0  | 67.0  | 68.0  | 39.0  | 71.0  | 75.0  |
| $M_{\text{min}} / M_i$ | 0.7053 | 0.8375 | 1.0   | 0.9853 | 0.9710 | 0.9437 | 0.8933 |
| Vehicle reliability indicators, Rl | 90.0  | 71.0  | 70.0  | 71.0  | 72.0  | 73.0  | 75.0  |
| $R_{\text{max}} / R_i$ | 0.7778 | 0.9859 | 1.0   | 0.9859 | 0.9722 | 0.9589 | 0.9333 |
The calculation results by formula (7) using the data of the long-term observations are presented in the form of a graph of the dependence of the efficiency of driving a heavy-duty pit truck on the driver’s length of service (Figure 4).

The graphs presented in the work (Figure 1-3) clearly show the efficiency of driving a vehicle depending on the driving style. The discrepancies between the efficiencies of the lean and aggressive driving styles by individual efficiency indicators vary over a wide range depending on the driver’s length of service.

![Graph](image.png)

**Figure 4.** The dependence of the efficiency of driving a BelAZ-7540B dump truck on the driver’s length of service in mountain conditions.

5. **Conclusions**

1. We proposed a methodology for evaluating the efficiency of driving a vehicle. We experimentally established the dependences of the efficiency of driving a vehicle on the driver’s length of service, as well as the limits of changes in the efficiency indicators using the lean and aggressive driving styles.

2. We developed a mathematical model of the dependence of the driving efficiency on the driver’s length of service, which is congruent with the results of the experimental studies for the mountain conditions of the Republic of Tajikistan.

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