Justification of efficiency of route fuel consumption norms for trucks operated in tropical conditions

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Abstract. Over the past decade, the economies of Southeast Asian countries, including Vietnam, have been developing dynamically, which leads to an increase in demand for the transportation of goods and passengers. At the same time, in a number of countries in this region, there is no state regulation in the field of rationing fuel consumption of trucks in real conditions. Therefore, improving the current fuel rationing system is an urgent task when performing cargo transportation in the tropics. The paper offers a justification for rationing fuel consumption of trucks performing transport work on permanent routes in tropical conditions on the example of Vietnam.

1. Introduction
In studies on fuel rationing in tropical conditions, experimental research was carried out in the Socialist Republic of Vietnam (SRV) for vehicles that perform cargo transportation on permanent routes. In the course of conducting research to analyze the possibility of using route fuel consumption regulation in Vietnam for trucks that perform transportation on established routes (often implemented when fulfilling transport orders in the construction industry), in accordance with the previously analyzed data [1,2,3] and the set goals [4,5], the tasks of choosing an experimental motor transport enterprise, collecting statistical information on fuel consumption on different routes, etc., were solved.

On the basis of the obtained approximations of average route fuel consumption, taking into account the data of the combined statistics on the variation of the studied random variables, in order to conduct a more detailed study, the standards of hard (85% quantile) and soft (95% quantile) restrictions were calculated for the experimental truck models.

The main effect of the introduction of route rationing of fuel consumption into the practice of a motor transport enterprise is manifested in the discipline of drivers [6,7,8] when organizing more precise control over fuel consumption on the basis of reasonable norms. This makes it possible to make stricter demands on drivers without overestimating the standard. To assess the effectiveness of the study, an approximate calculation of the economic efficiency of using the calculated route fuel consumption standards in an experimental motor transport enterprise was also performed.
2. General analysis of the efficiency of rationing fuel consumption for individual sub-groups (clusters) of vehicles

Let us assess the gain in fuel costs arising from the implementation of the fuel rationing system, at which the standard, i.e. the upper limit of the value of specific fuel consumption, within which the fuel costs are considered as acceptable, is assigned taking into account the properties and characteristics of the vehicle’s route, in comparison with the standard norm assigned as a whole, for a generalized group.

Let the probability distribution of specific fuel consumption have the form shown in Fig. 1 with the parameters $M_i$ - mathematical expectation and $\sigma$ - standard deviation (In this estimated conclusion and further calculations, we rely on the form of the normal distribution, as the most common, and indeed manifested for the collected fuel consumption values separately along the routes. However, it should be noted that the conclusion formulas are valid for various types of probability distributions).

Figure 1 shows $M_i$ – the mathematical expectation of fuel consumption on the i-th route, $S_i$ and $S_\Sigma$ - various assigned standards (individual and generalized), as well as the probability distribution density function of the true specific fuel consumption on the i-th route $f(x)$ with color-marked zones: light green – that do not make any difference in the formation of total fuel consumption, dark green (swamp)- that make a difference.

Let's first determine the possible fuel consumption at a certain given permissible upper limit (standard norm) $S$, based on the fact that with a real consumption of a technically serviceable car less than $S$, with a probability $k$ (in fact, it can be called the "temptation coefficient"), the consumption will be equal to $S$, - this is a fuel drain that is still widely implemented in real practice in Vietnam, and insufficient care of the vehicle, not optimal driving mode, poor quality control of technical condition, etc., - indeed, when the vehicle is operated on routes with low difficulty coefficients that require less fuel consumption, the driver may pay less attention to factors that lead to increased fuel consumption, especially if the standard is assigned for a generalized group of vehicles-operation on all routes of the enterprise as a whole, or even a national standard norm. According to preliminary estimates, the coefficient $k$ can range from 0.3 to 0.8. If the actual fuel consumption is greater than $S$, the value of the specific fuel consumption added to the weighted average value does not change. This zone ($x>S$) is a zone of risk, a zone of social discomfort, tension, because at real consumption $X$, the driver is required to spend no more than $S$. As usual, however, when the standard is set correctly (95% quantile, and even in the case of particularly significant parameters, such as those affecting the safety of traffic, or when rationing strategically important resources, such as in certain cases fuel in the SRV, 85% quantile), this zone includes cases related to the reasons listed above, set by not quite efficient operation of the trucks.
Let's determine the weighted average value of the "additional, excess" value of the specific fuel consumption:

$$Q_s = k \cdot \int_{g_1}^{S} f(x, M, \sigma)(S - x)dx =$$

$$= k \cdot \int_{g_1}^{S} (f(x, M, \sigma) \cdot S)dx - k \cdot \int_{g_1}^{S} (f(x, M, \sigma) \cdot x)dx =$$

$$= k \cdot S \cdot F_0\left(\frac{S - M}{\sigma}\right) - k \cdot \int_{g_1}^{S} (f(x, M, \sigma) \cdot (x - M + M)dx$$

where $g_1$ is the lower limit of integration, in the general case (for a normal distribution, especially with small coefficients of variation of a random variable, for the convenience of integration, it is usually taken $-\infty$).

$F_0(z)$ - Cumulative function of the probability distribution law of the normalized random variable (for the standard norm selected in accordance with the methodology for a given random variable, $F_0((S-M)/\sigma)$ is equal to 0.85 under a hard constraint and 0.95 under a soft constraint).

Let's take $y = x - M$ and transform the last term:

$$\int_{g_1}^{S} (f(x, M, \sigma) \cdot (x - M + M)dx = \int_{y = -\infty}^{+\infty} (f(y, 0, \sigma) \cdot y)dy +$$

$$+ \int_{g_1}^{+\infty} (f(x, M, \sigma) \cdot M)dx = - \int_{-\infty}^{S-M} (f(y, 0, \sigma) \cdot y)dy + M \cdot F_0\left(\frac{S - M}{\sigma}\right) =$$

$$= -\sigma \cdot \int_{S-M}^{+\infty} (f(z, 0, 1) \cdot z)dz + M \cdot F_0\left(\frac{S - M}{\sigma}\right)$$

Finally, we get:

$$Q_s = k \cdot \left[ (S - M) \cdot F_0\left(\frac{S - M}{\sigma}\right) + \sigma \cdot \int_{S-M}^{+\infty} (f(z, 0, 1) \cdot z)dz \right] \quad (1)$$

So, for values $S_\Sigma > S_i$ (taking into account that $S_i = M_i + r \cdot \sigma_i > M_i$), we have for the difference in the values of excess specific fuel consumption:

$$Q_{S_\Sigma} - Q_{S_i} = k \cdot \left[ (S_\Sigma - M_i) \cdot F_0\left(\frac{S_\Sigma - M_i}{\sigma_i}\right) + \sigma_i \cdot \int_{S_i-M_i}^{+\infty} (f(z, 0, 1) \cdot z)dz \right] -$$

$$- k \cdot \left[ (S_i - M_i) \cdot F_0\left(\frac{S_i - M_i}{\sigma_i}\right) + \sigma_i \cdot \int_{S_i-M_i}^{+\infty} (f(z, 0, 1) \cdot z)dz \right] =$$

$$= k \cdot \left[ (S_\Sigma - S_i) \cdot F_0\left(\frac{S_\Sigma - M_i}{\sigma_i}\right) + (S_\Sigma - M_i) \cdot (F_0\left(\frac{S_\Sigma - M_i}{\sigma_i}\right) - F_0\left(\frac{S_i - M_i}{\sigma_i}\right)) \right] -$$

$$- k \cdot \sigma_i \cdot \int_{S_i-M_i}^{S_\Sigma-M_i} (f(z, 0, 1) \cdot z)dz \quad (2)$$
This expression characterizes the expected difference in fuel consumption for any one i-th route when assigning an individual norm compared to the assigned general group standard norm (for all routes at once), which in General can be either positive or negative.

Let us simplify the expressions presented above and consider the total difference for all routes of the group (enterprise) based on the specific consumption.

Since \( S_i = M_i + \sigma_i \cdot r \), and \( \sigma_i = M_i \cdot \upsilon_i \) and \( F_{\Theta}(r) = \Theta \) – is the level of the specified limit of the standard (for example, \( \Theta = 0.85 \), and \( r \) is the corresponding quantile), we obtain from (1):

\[
Q_{S_i} = k \cdot \left[ \sigma_i \cdot r \cdot F_{\Theta}(r) + \sigma_i \cdot \int_r^{+\infty} (f(z,0,1) \cdot z)dz \right]
\]

(3)

Table 1. Values of the elements of formula (3) for different values of the level of the specified norm limit.

| \( \Theta \) | r   | \( \int_r^{+\infty} (f(z,0,1) \cdot z)dz \) |
|------------|-----|---------------------------------------------|
| 0.85       | 1.037 | 0.233                                      |
| 0.95       | 1.64  | 0.104                                      |

Assuming that the influence of variations in parameters that affect fuel consumption, but are not related to the characteristics of the routes (such as the technical condition of the truck, various driver qualities, etc.), on different routes served by the same automobile enterprise, can be assumed to be very close for this estimate we will accept the invariance of the coefficient of variation for the spread of values of specific fuel consumption by trucks of the same model on one (i-m) route: \( \upsilon_i = \upsilon \forall i \). From this assumption we get:

\[
Q_{S_i} = k \cdot \upsilon \cdot M_i \left[ r \cdot \Theta + \tau \right] = C_k \cdot \upsilon \cdot M_i ,
\]

Let's take the notation: \( C_k = [r \cdot \Theta + \tau] \).

Then, to combine routes into one group, we sum up the \( Q_{S_i} \) for all I-th routes with weights – the probabilities of finding a truck on the i-th route, i.e. with the part of the i-th route in the total volume of traffic (for the truck model under consideration):

\[
Q_{\Sigma} = \sum P_i \cdot Q_{S_i} = C_k \cdot \upsilon \cdot \bar{M}
\]

In the case of calculating the considered value for the standard assigned for the entire combined group of routes, we have the following expressions:

\[
S_2 = \bar{M} + r \cdot \sigma_u,
\]

where \( \sigma_u \) - is the standard deviation for the combined route group, determined from:

\[
\sigma^2_u = \sum_{i=1}^{n} P_i \sigma^2_i + \sum_{i=1}^{n} P_i (M_\Sigma - M_i)^2 - \upsilon \cdot \sum_{i=1}^{n} P_i M_i^2 + \sum_{i=1}^{n} P_i (M_\Sigma^2 + M_i^2 - 2 \cdot M_\Sigma \cdot M_i)^2 =
\]

\[
= \sum_{i=1}^{n} P_i (M_i^2 (1 + \upsilon^2) + M_\Sigma^2 - 2 \cdot M_\Sigma \cdot M_i)^2 = -M_\Sigma^2 (1 + \upsilon^2) +
\]

\[
+(1 + \upsilon^2) \sum_{i=1}^{n} P_i M_i^2 + M_\Sigma^2 \cdot \upsilon^2 = (1 + \upsilon^2) \cdot \left( \sum_{i=1}^{n} P_i M_i^2 - M_\Sigma^2 \right) + M_\Sigma^2 \cdot \upsilon^2
\]

Thus, the coefficient of variation of the combined group is determined by:
\[ \nu_{i}^{2} = \frac{\sigma_{M_{i}}^{2}}{M_{i}^{2}} = (1 + \nu_{i}^{2}) \cdot \frac{D(M_{i})}{M_{i}^{2}} + \nu_{i}^{2} = (1 + \nu_{i}^{2}) \cdot \nu(M_{i})^{2} + \nu^{2} \]

where \(D(M_{i})\) and \(\nu(M_{i})\) are the operators of taking, respectively, the variance, the coefficient of variation for the sample consisting in this formula of the mathematical expectations of specific fuel consumption on the \(i\)-th route.

Therefore, the difference in expected fuel consumption can be estimated using the formula:

\[ Q_{S_{i}} - Q_{\Sigma} = \tilde{M} \cdot C_{k} \cdot (\sqrt{\nu_{i}^{2} + (1 + \nu_{i}^{2}) \cdot \nu(M_{i})^{2}} - \nu) \]

and it is obviously positive, i.e. the expected fuel consumption in the case of setting the standard for the entire combined group at once will be higher. It should be noted that in any case of inequality of coefficients of variation for statistics on different routes, the excess of expected fuel consumption is also proved when assigning a combined standard using the same method.

Let \(\nu_{i} \neq \nu_{j}\) be at least for some \(i, j\). Then for the sum of individual routes we have the expression:

\[ Q_{\Sigma} = \sum P_{i} \cdot \sigma_{i} \cdot C_{k} = M(\sigma_{i}) \cdot C_{k} \]

where \(M(\ldots)\) is the operator for taking the mathematical expectation from the corresponding sample. Let's consider expressions for a given generalized standard norm \(S_{2}\). While:

\[ D(\sigma_{i}) = -(M(\sigma_{i}))^{2} + M(\sigma_{i}^{2}) \geq 0 \Rightarrow (M(\sigma_{i}))^{2} \leq M(\sigma_{i}^{2}) \]

For the combined group we have:

\[ Q_{S_{2}} = C_{k} \cdot \sigma_{\Sigma} \]

Compare the squares of values \(Q_{\Sigma}\) and \(Q_{S_{2}}\):

\[ Q_{S_{2}}^{2} = C_{k}^{2} \cdot M(\sigma_{i})^{2} \leq Q_{S_{2}}^{2} = C_{k}^{2} \cdot \sigma_{\Sigma}^{2} = C_{k}^{2} \cdot (M(\sigma_{i}^{2}) + D(M_{i})) \]

Consequently, the expected fuel consumption when assigning individual route standards will be less than when assigning the general group standard by the same method, and the difference will be the greater, the more the complexity of the routes differ.

The calculation of the difference in the total value of the specific fuel consumption when setting different normative boundaries, carried out according to formula (2), concerns the consumption of one model for any one route. To calculate what the effect will be for all routes of the same model, you need to find the average value of such differences for each route, and in the case when the load on the routes is not clearly defined, you can find a simple average value. If the company's work program is stable enough, and the route load is clearly set for a long time, it is more correct to take a weighted average value, where the average daily mileage of vehicles operated on the corresponding route is used as a weight.

An illustration of the relative positions of functions and compared regulatory boundaries for each route used for calculating the difference in total fuel consumption using formulas (2) is shown in figure 2 a,b.

Here in figure 2a shows a separate fragment of the entire field of functions with the notation and parameters consistent with figure 1, used to construct the output of formula (2), and with the shape and color representation consistent with figure 2b, and in Fig. 2b shows the complex formation of the difference in total consumption.

The density functions of the probability distribution of the specific fuel consumption separately for each route are shown in green, while the specific fuel consumption \(Q\) is given on the abscissa axis, and the route number is indicated on the ordinate axis. For each route, the standard \(S_{i}\) calculated for this route is shown in blue. The red color indicates the limits of the \(S_{i}\) standard defined for the entire set of
vehicles, based on the same principle as for individual routes, i.e. the corresponding quantile (the very distribution of probabilities for fuel consumption for the generalized group of trucks is shown in red at the position of route No. 11).

The zones between $S_i$ and $S_2$ are shown in different colors depending on whether the total flow consumption for a particular route decreases (red, $S_1 < S_2$) or increases (blue, $S_1 > S_2$). The data for constructing the illustration are taken from the results of calculations for the KAMAZ-55111 model, dry period, with a soft assignment of the standard, i.e., the cut-off probability is 0.95. It should be noted that when using vehicles in the tropics, it is necessary to consider separately the two seasons of operation - dry and rainy (wet).

To calculate the generalized effect from the use of individual route standards for each individual vehicles model, after calculating the averaged values of the effect both in absolute values (l/100 km.) and in relative (%) for each season, these values were averaged over the entire year (i.e. for two seasons) to obtain the resulting performance indicators for each individual truck model.

To obtain the total final effect, the performance indicators for each model were added with weights equal to the part of individual truck models in the enterprise.

At the same time, a generalized standard can be assigned for each vehicles model as a whole throughout the whole year, as it happens now in Vietnam, and with division by seasons. In tropical climatic conditions (for example, in Vietnam), the division into dry and rainy seasons adopted in this work seems to be the most logical, as noted above. Further calculations, which were carried out using the formulas presented above, used the previously obtained values for the route norms for specific fuel consumption separately by seasons for each of the considered car models, together with the values of the mathematical expectation of consumption obtained after factor analysis, the standard deviation for the probability distributions of specific fuel consumption, obtained from the collected statistical data separately for routes and seasons. The corresponding values were also determined and used in the calculation for a generalized group of trucks (for each model separately) per season. For a complete comparison, we used data on currently existing single (model-based) standards in the SRV.

Although for traction and economic indicators, it is customary to use the assignment of standard norms for 85% quantile ("soft" standard), calculations according to a specially created program were also carried out for a more rigid option - 95% quantile. The effect of applying route rationing was also calculated in relation to the standards assigned in an individual motor transport enterprise for a generalized group of trucks (with a natural division by season and model), as well as in relation to the currently accepted industry model standards.

In accordance with the calculations, it can be concluded that even with the appointment of "soft" standards, the gain even in relation to the appointment of a norm for the generalized group of routes will be from 3.4% to 4.1%, depending on the redistribution of the volume of transport work along the routes in the enterprise, and in comparison, with the industry-wide standard, the gain reaches 4.4% - 5%. In absolute terms, this effect for the pilot enterprise is from 94 to 140 tons of fuel per year. When using more stringent rationing, the effect can range from 66 (2.4%) to 197 tons per year. Even assuming the above-described "temptation coefficient" of 0.5 in the current diesel prices in Vietnam, the minimum effect is 0.89 billion Vietnamese Dong or 2.7 million rubles.
Figure 2. Illustration of finding the complex effect of applying separate route standards on the specific fuel consumption in an enterprise.
(a) – a separate element; (C) – a composition of jointly considered probability distribution densities for specific fuel consumption on individual routes of the enterprise.

3. Conclusion
Based on the above, it can be stated that in Vietnam, as in other countries of South-East Asia, the trend of increasing cargo turnover continues, with a corresponding increase in the number of vehicles in operation. This leads to an increase in fuel consumption in road transport companies. To reduce operating costs during cargo transportation, it is necessary to improve methods for calculating fuel consumption standard norms based on differentiated consideration of many factors that affect fuel consumption. The proposed justification for rationing fuel consumption by trucks will make it possible to more correctly assign fuel consumption standards for vehicles performing transport work in the tropics.
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