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Efficiency of Vehicle Operation

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ABSTRACT

The paper presents the results of researching the mileage of vehicle efficient operation (MVEO) based on the method of using the techno-economic criterion (TEC). As a result of our work, we have defined and substantiated the MVEO for motor vehicles operated in the conditions of St. Petersburg and the Leningrad region, and calculated the lifetime of motor vehicles with the use of the TEC. In defining MVEO and in the use of the TEC an important role was played by complexity of running repair (RR) of the rolling stock not regulated by the manufacturers of vehicles of these brands. It has been found that the value of MVEO is influenced by a number of various factors, for example: Efficiency of the production-technical base, qualification of the personnel, operating conditions (road, transport, etc.), and the level of instrumentation. Each of them has its specific weight in the MVEO value, but using the work load of RR parameter is explained by its complexity, and all these factors influence its value in varying degree.

Keywords: Mileage of Vehicle Efficient Operation, Techno-economic Criterion, Vehicle Efficient Operation
JEL Classifications: L62, L91, R49

1. INTRODUCTION

One of the most common ways to limit operation of a product is the method of using the techno-economic criterion (TEC). This method comes down to defining the total specific cost of maintenance (M) and running repair (RR) and its minimization. The difficulty in this case is that the duration of vehicle service is a random value that depends on many factors, such as the repairability of the vehicle, operating conditions, mileage since the beginning of the vehicle operation, availability of spare parts, qualification of drivers and maintenance workers, the degree of mechanization of the production processes, work organization, etc. This greatly complicates the process of accurately predicting the M and RR system performance.

However, if we assume that for a particular type of rolling stock (the mileage of a motor vehicle efficient operation (MVEO) should be determined for each specific model of motor vehicles), and specific conditions of use, the duration and work regulations are rigidly defined by the manufacturer of the equipment being operated, which allows to remove a number of uncertainties and greatly simplifies the algorithm of system analysis Terentyev, 2008; Terentyev, 2011; Terentyev et al., 2013; Terentyev, 2013; Terentyev and Yuzhan, 2014; Terentyev and Prudovsky, 2014a; Terentyev and Prudovsky, 2014b; Terentyev and Prudovsky, 2014c; Terentyev and Prudovsky, 2015; Terentyev, 2015a; Terentyev, 2015b; Terentyev 2015c; Terentyev et al., 2015; Terentyev, and Belyaev, 2015; Belyaev and Menukhova, 2014).

2. METHODS

One of the variants of using TEC, when studying the model is down to determining the total cost of maintenance and repair, and its minimization (Ci) with regard to the specific cost of the vehicles (Ca). The minimum cost corresponds to the optimal value of MVEO (Lopt). With that, the cost of M is equal to:

$$C_m = CS_m \, Wl_{TO}, \text{ rubles,} \quad (1)$$

Where CS_m is the specific cost of maintenance for a particular type of service

Wl_{TO} is the workload at a specific mileage.

The cost of RR is equal to:

$C_{rr}=CS_{rr}\ Wl_{rr}$, rubles, (2)

Where, CS_{rr} is the specific repair costs;

Wl_{rr} is the workload of RR at a specific mileage.

Next, the total costs are calculated:

$C_{m\&rr}=C_{m}+C_{rr}$, rubles. (3)

With increasing the mileage, the costs of M and RR increase (the resource of parts or aggregates decreases, and the repair costs increase), and the specific cost of the car decreases.

This expression is a target function, the extreme values of which correspond to the optimal solution:

$C_{\Sigma}=C_{m\&rr}+C_{a}$, rubles, (4)

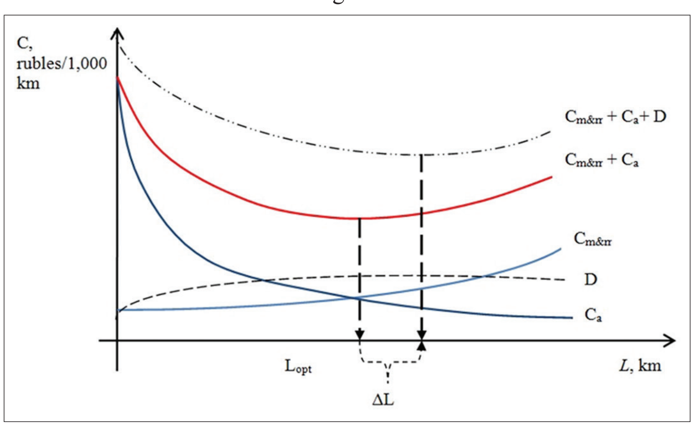
Where C_a is vehicle specific cost

In this case, the optimal solution (the L_{opt} value) corresponds to the allowable costs.

The value of the target function of the optimal value is determined graphically or analytically if the following dependencies are known: $C_M=f(l)$, $C_{RR}=\psi(l)$. In this case, the optimal solution (the L_{opt} value) corresponds to the allowed value of cost (Figure 1).

In some works where TEC is used (this method has been repeatedly used to determine the value of the vehicle mileage to decommissioning), the operating revenue is also calculated. In this case, as a rule, value Lopt increases by the amount of ΔL, thereby increasing the operation life of the vehicle. In particular, it is said: "There are values of a bus utilization coefficient where termination of its operation ensures the minimum of maintenance and RR expenses with regard to its cost; the main disadvantage of these methods is the lack of accounting for the operating revenues.

Figure 1: Defining vehicle mileage to decommissioning by the value of the target function



It is necessary in the present market conditions for foreign buses that had been purchased after substantial mileage, since there are no regulatory or recommended values of the time of operation to decommissioning; bus mileage to decommissioning; the utilization coefficient (UC min). It is necessary to introduce a comprehensive economic criterion for determining the ultimate state of buses."

We cannot agree with some of the provisions in this quote:

1. If the time of limit operation of foreign buses is unknown, it does not mean that it does not exist.
2. By the way, operating revenues are not acceptable in the domestic market as a factor for defining MVEO. It is known that today revenues are generated with regard to available rates, which leads to shifting the burden of rolling stock operation costs to the shoulders of the consumer of the services.
3. Lifecycle or mileage to decommissioning of buses in this paper is defined for an enterprise that gets profit; however, the problem is the following: What is to be done if a motor vehicle is operated by an individual, or an organization for which the motor vehicle is the main source of income.

The study was further focused on obtaining and processing the experimental data in order to determine the fixed MVEO value for the rolling stock of a specific type. To solve this problem, it is necessary to define the analytical and graphical dependence of the specific labor input for RR (man-hours/1,000 km) in the mileage from the beginning of operation for the studied rolling stock.

$$C, L_{\text{opt}}\left(t_{\text{rr}}\right) \rightarrow \text{opt} \quad . \qquad (5)$$

Where C is the cost of maintenance and RR of the rolling stock, rubles/thousand km;

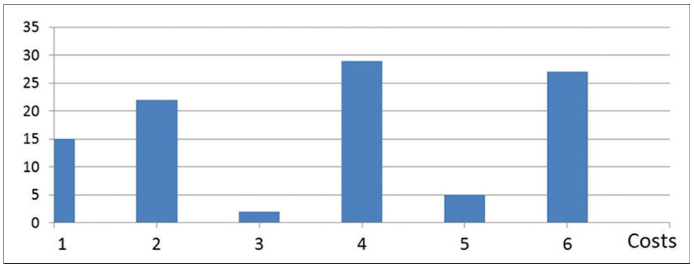
L is vehicle mileage, thousand km;

t_{rr} in the labor input for rr, man-hours/1,000 km.

It is not superfluous here to explain why exactly the indicator of specific manpower for RR has been chosen as the defining value of MVEO. The cost of RR has always been a considerable part of operating costs of transportation. If we talk about the cost of maintenance and repairs, they are 3 … 7 times higher than the initial cost of the vehicle over its lifecycle. On the average, each year these costs are 770 rubles per truck, 550 rubles per car, and 1,230 rubles per bus. In the structure of road transportation cost, they amount on the average to 10 … 13. Separate sources provide the following data. Figures 2 and 3 show the distribution of operating costs associated with rolling stock operation, which signifies that cost of fuel and repair and salary of drivers make a significant share. In the cost of transportation, the share of variable expenditures is about 73% (Figure 4).

In recent years, there has been a trend of increasing the "costs of rolling stock maintenance and RR." This is primarily due to increased cost of spare parts and materials. The cost of spare parts for new models of imported vehicles is much higher than the cost of spare parts for domestic vehicles. This primarily applies to

Figure 2: Distribution of operating expenses by cost items



(1) Fuel cost; (2) repair and maintenance cost; (3) wear and repair of tires; (4) basic salary; (5) depreciation of fixed assets; (6) overheads

Figure 3: Tip-truck operating cost

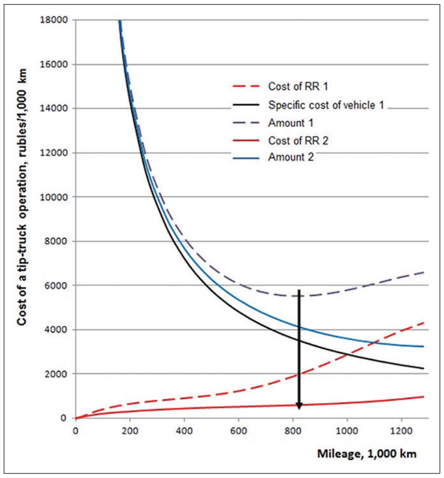
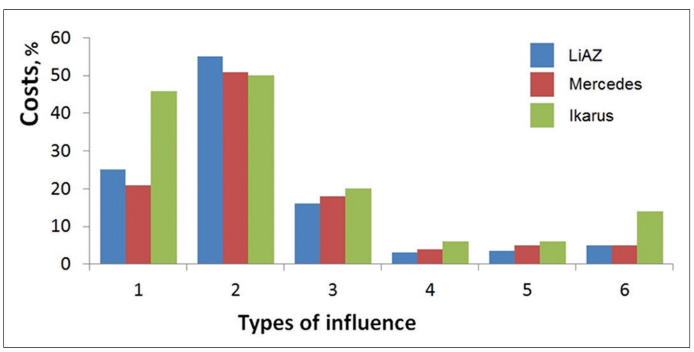


Figure 4: Rolling stock repair and maintenance cost distribution



(1) Overhaul; (2) RR; (3) Maintenance-2; (4) Maintenance-1; (5) Daily service; (6) Tires

basic parts of engines and transmissions. For example, the cost of a crankshaft for the "Mercedes-Benz" eight-cylinder engine in 4… 5 times the value of a crankshaft for the KAMAZ-740 engine. Thus, the tendency of displacing domestic vehicles with imported models results in impossibility of performing major overhaul of foreign vehicles for a specific fleet.

For experimental study of changes in the complexity of maintenance and RR, depending on the mileage since the beginning of vehicles operation, the following types of Scania vehicles operated in St. Petersburg and the Leningrad region were chosen:

1. Scania P114 GA 6×4 NZ 340 articulated lorries (the maximum load on the rear trolley is 21,000 kg) – 48 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 80,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0…800,000 km.
2. Scania P114 GA 4×2 NA 330 articulated lorries (the maximum load on the rear trolley is 11,500 kg) – 24 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 80,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0 … 800,000 km.
3. Scania P114 CB 6×4 HZ 380 tip trucks (capacity of 26,500 kg) – 28 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 80,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0 … 800,000 km.
4. Scania P114 GA 4×2 NA 330 tip trucks (the maximum load on the rear trolley is 11,500 kg) – 24 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 80,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0 … 800,000 km.
5. Chevrolet passenger cars (5 persons) operated as cabs – 35 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 15,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0 … 150,000 km.
6. BMW passenger cars (5 people) operated by individuals – 33 units. In the studied conditions, the interval, and, therefore, the accounting cycle is 20,000 km. The values of the required manpower input for RR in order to address vehicle failures was determined when the vehicle mileage was 0 … 250,000 km.

In the experiment, the size of sampling is determined based on two conditions:

- Efficiency (the sample size should be minimum);
- Obtaining reliable data about the studied phenomenon.

With that, the sample of the mileage factor since commissioning is a set of elements: x1, x2,… xn taken at random from the general population. The general population is understood as a finite or an infinite set of elements joined together by a qualitative or quantitative argument. The size of the sampling is less than the size of the general population, and therefore the estimates derived from analysis of sampling populations always have an error. The sampling size is determined with regard this error.

Thus, the method of calculating the required sample size was parametric, that is, when the distribution law was known.

Before determining the size of the sample, normality of the mileage factor distribution from the beginning of operation was checked for the following characteristics:

- The coefficient of variation – $V(x)$, if $V(x) < 0.33$, the distribution of the random variable belongs to the normal law.
- The amplitude of variation is equal to 6σ - the extreme values are at the distance of 3σ on either side, and are defined by the formula:

$$x - 3\sigma(x)<x<x + 3\sigma(x), \quad (6)$$

Where x is the statistical value of the mathematical expectation of a random value;

$\sigma(x)$ is the statistical value of the average quadratic deviation of a random value.

If the majority of values from the general population decrease with the probability of 95% into the predefined interval 6σ, the distribution law of the random value may be considered normal.

The Pearson criterion. If the experimental value is less than the theoretical (the highest value), the hypothesis of normal distribution of the random value is confirmed.

With that, the distribution law is chosen according to the standard methods.

The sampling size depends on the standard sampling error and the degree of characteristic variation in the population. Reducing the sampling size always involves increasing the standard sampling error, and, therefore, decreasing the assessment accuracy (Belyaev and Menukhova, 2014).

For a normal distribution, the sampling size is calculated by the formula:

$$n = (t^2 \ldots \sigma^2)/\varepsilon^2, \quad (7)$$

Where t^2 is the inverted value of the Laplace function;

σ^2 is the assessment dispersion;

ε^2 is the computing density of a sample average (x).

Provided that accuracy (ε) may be expressed in terms of relative precision $(\varepsilon_0) + \varepsilon_0 = \varepsilon/x$, the formula may be calculated as follows:

$$N> [(t^2 \bullet \sigma^2)/(\varepsilon^2 \bullet x)] >(t^2 \bullet V^2)/\varepsilon_0^{\,2}, \quad (8)$$

Where V is the coefficient of variation.

In engineering, the 5% significance level is most often accepted, which corresponds to $t = 1.96$.

The general population of values was more than 50 units, for each type of rolling stock, which substantially exceeds the sampling size. Adopting $\varepsilon_0 = 0.1$, with the 5% significance level $\alpha = 0.05$, and the variance equal to 0.3, the sampling size of observations amounted to $n = 34.6$ (35).

Thus, in order to obtain reliable data about the mileage factor since the start of operation, with the accuracy of $\varepsilon_0 = 10\%$, significance level of 5%, and the confidence level of 95%, one should select not < 35 values.

In the next stage of processing the experimental data, the correlation and regression analysis was used. The statistical correlation between the experimental data was established with the use of correlation analysis. The basic statistical characteristics of mathematical relations were calculated.

The tightness of correlation was estimated by the value of pair correlation r (in case of linear correlation between the indicators), and correlation ratio η (in the case of nonlinear correlation).

The parameters of the equations are calculated through the systems of normal equations:

$$na_0+a_1\sum x+a_2\sum x^2\ n=\sum y$$

$$a_0\sum x+a_1\sum x^2+a_2\sum x^3\ n=\sum xy \quad (9)$$

$$a_0\sum x^2+a_1\sum x^3+a_2\sum x^4 n=\sum x^2y$$

The significance of correlations was assessed by student's t-test. Model's adequacy to experimental data was checked using the F-ratio test. The experimental data were processed using a personal computer in EXCEL.

The value of RR labor input for the studied rolling stock was determined after various mileages. Further, for simplifying data processing and presentation:

1. Articulated lorries ScaniaP114 GA 6×4 NZ 340 and ScaniaP114 CB 6×4 HZ 380 were joined into a single technologically compatible group and will be referred to as "truck – articulated lorry;"
2. Tip-trucks ScaniaP114 CB 8×4 HZ 380 will be referred to as "truck – tip-truck;"
3. Chevrolet cars will be referred to as "car – cab;"
4. BMW cars operated by private persons will be referred to as "passenger cars."

The study was performed on the following values of vehicles mileages from the beginning of operation:

1. "Truck – articulated lorry" - 0.900 thousand km;
2. "Truck – tip-truck" - 0.800 thousand km;
3. "Car – cab" - 0.200 thousand km.
4. "Car" - 0.250 thousand km.

3. RESULTS

Basing on modern experimental data and the prompt method of studying the changes in labor input into running report for the four groups of cars, one can determine analytical and graphic dependences that allow to determine the trends and intensity of changes in the technical state of vehicles by the integrated indicator of RR labor input. It has been established that for all four cases changes in the RR labor input occur according to the polynomial law, and are described by the quartic rational function.

This corresponds to the statement that in case of gradual failures, changes in the parameter of technical state of a particular product, or the average value for a group of products may be described analytically quite well by function:

$$y = a_0 + a_1 l + a_2 l^2 + a_3 l^3 + \ldots + a_n l^n \quad (10)$$

Where a_1, $a_2 \ldots a_n$, are the coefficients that determine the nature and the degree of y dependence on l;

a_0 is the initial value for the technical state parameter;

l is running hours.

The obtained data is summarized in Table 1.

Further study of the dependencies shown in Table 1 is reduced to the sequential determination of the first and second derivatives to the location of the inflection point of the second kind. Its position determines the change in the intensity of increasing the RR labor input parameter. The results of calculations are shown in Table 2.

4. DISCUSSION

The results may be explained in the following way: At a certain moment (mileage) a change occurs in the intensity of increasing the integrated index – RR labor input; the duration vehicles stay at service stations or in the maintenance and repair areas of motor transport enterprises increases; work complexity increases, and complex and expensive components and assemblies fail and require replacement. As a consequence, maintenance is unable to ensure meeting necessary requirements for ensuring working order of vehicles and its operation safety. All these situations result in a considerable increase in the cost of the motor vehicle. Therefore, the authors believe that in modern conditions, the value of a motor vehicle effective operation (MVEO) should be determined according to the following algorithm:

1. Accumulating primary information about increasing RR labor input individually for each motor vehicle.
2. Processing the obtained data using the method shown in the paper and obtaining the functional dependency for changing the RR labor input.
3. Determining the point of changing the intensity of increasing the studied parameter for each individual vehicle (definition of MVEO).
4. Comparing the data for a certain brand of vehicles and developing recommendations about the MVEO value.

4.1. Applying MVEO to the Operation Period of Motor Vehicles

The switching from MVEO to determining the duration of motor vehicle operation by the TEC, the following was done during the study:

1. RR labor input was multiplied by the cost of performing the appropriate kind of technical works.
2. The costs of maintenance and RR were summed up, resulting in a single dependency (Cost of M and RR).
3. The dependence of the specific cost of a vehicle per 1000 km of mileage was built from the beginning of vehicle operation (specific cost/1000 km).
4. The obtained two dependencies were summed up for the relevant mileages since the beginning of operation (the sum of costs).

Table 1: Changing the RR labor input parameter

Rolling stock type	Analytical dependence	R^2
Car	y=1E-08×⁴−4E-06×³+0.0003×²+0.0011×+0.0069	0.9629
Car–cab	y=3E-09×⁴−8E-07×³+5E-05×²+0.0027×−0.0082	0.9363
Truck–tip-truck	y=−2E-12×⁴+5E-09×³−5E-06×²+0.0023×−0.0166	0.9806
Truck–articulated lorry	y=−9E-13×⁴+3E-09×³−2E-06×²+0.001×+0.0246	0.973

RR: Running repair

Table 2: The results of studying obtained functional dependencies

Rolling stock type	Coefficients	Coefficients values at f(x)	f'(x)	f"(x)	x at f"(x)
Car	a_4	1.00E-08	4E-08	1.2E-07	170.710
	a_3	−4.00E-06	−1.2E-05	−2.4E-05	
	a_2	0.0003	0.0006	0.0006	
	a_1	0.0011	0.0061		
	a_0	0.0069			
Car–cab	a_4	3E-09	1.2E-08	3.6E-08	107.49
	a_3	−8.00E-07	−2.4E-06	−4.8E-06	
	a_2	5.00E-05	0.0001	0.0001	
	a_1	0.0027	0.0061		
	a_0	0.0082			
Truck–tip-truck	a_4	−3.00E-12	−1.2E-11	−3.6E-11	500.00
	a_3	7.00E-09	2.1E-08	4.2E-08	
	a_2	−6.00E-06	−1.2E-05	−1.2E-05	
	a_1	0.0022	0.0061		
	a_0	0.0065			
Truck–articulated lorry	a_4	−3E-14	−1.2E-13	−3.6E-13	695.70
	a_3	1.00E-09	3E-09	6E-09	
	a_2	−2.00E-06	−4E-06	−4E-06	
	a_1	0.001	0.0061		
	a_0	0,0128			

5. The value of the effective vehicle operation mileage (the inflection point) was found.

Let us provide a variant of using TEC for the vehicles studied during operation, in particular, for tip-trucks (Figure 3).

It can be assumed that the values of vehicle service life obtained by using the TEC will differ even within the framework of studying motor vehicles of the same vehicle model. This may be explained by:

1. Different costs of vehicles
2. Different operating conditions
3. Different costs of maintenance and RR
4. Different costs of spare parts and assemblies.

In the diagrams, the dashed lines show the total rolling stock RR cost with regard to the specific cost of the vehicle, depending on the mileage since the beginning of operation. Index (1) is used to describe the results obtained in applying the method of calculating the complex indicator of RR labor input proposed by the authors in this paper, while index (2) is used in calculation using the classical method. In this case, it is clear that using classical method does not provide the possibility to use the TEC for the studied mileages and to determine the inflection point for the obtained functions.

This allows the authors to state that the suggested method of determining MVEO is more "engineering," and it can be used to obtain the values of motor vehicles operation life. The use of the TEC has adjusted the MVEO value obtained roughly by the results of studying functions in Table 2. Let us compare the values in Table 3.

The results obtained for defining the motor vehicle operation life with the use of TEC may seem biased, or highly undervalued from the point of view of the widespread practice of operating motor vehicles till complete failure. Therefore, we will present the data by the lowest value of a cab operation life (70,000 km):
1. Calculation of the operating cost for studied cabs (Table 4).
2. Calculation of income and profitability (Table 5).

The above values show that increasing the cost of maintenance and RR starts between 50 and 100 thousand km. In the same interval, the revenues from motor vehicle operation reduce. Profitability decreased from 23% to 15% (let us remind you that the minimum profitability in the transportation industry is about 17%), and during the next 50 thousand km, this indicator decreases to the unacceptably low value of 7.9%. This is the real data of an enterprise that is actively operating in the market of passenger transportation in St. Petersburg.

5. CONCLUSION

As a result of our work, we have defined and substantiated the MVEO for motor vehicles operated in the conditions of St. Petersburg and the Leningrad region, and calculated the lifetime of motor vehicles with the use of the TEC.

In defining MVEO and in the use of the TEC an important role was played by complexity of RR of the rolling stock, not regulated by the manufacturers of vehicles of these brands. The need to consider the amount of RR labor input was determined by the research performed at companies of St. Petersburg. It is the cost of vehicles RR that limits the effective mileage of vehicles in the current conditions.

It should be noted that the value of MVEO is influenced by a number of various factors, for example: Efficiency of the production-technical base, qualification of the personnel; operating conditions (road, transport, etc.), level of vehicle instrumentation, etc. Each of them has its specific weight in the MVEO value, but using the work load of RR parameter is explained by its complexity, and all these factors affect its value in varying degree. In the presence of experimental base, it is not hard to define the specific weight of each factor. The paper does not contain this material in order to keep the focus of the substantiating the necessity of forming a transportation sector for disposal of motor vehicles.

This paper will make it possible to use the results for economic assessment and optimization of work, and for increasing the efficiency of the "manufacturing – operation – disposal" system of vehicles operation. The subject has been studied in the initial stage. World practice shows that this area of activities does not have a sound scientific basis for further research, and the authors will continue studying this important subject.

Table 3: MVEO value

Rolling stock type	Vehicle mileage	
	By the change in the RR intensity, man-hour/ 1,000 km (MVEO)	By the techno-economic criterion, rubles/ 1,000 km (Operation life)
Car	170	195
Car–cab	107	70
Truck–tip-truck	500	660
Truck–articulatedlorry	695	970

MVEO: Mileage of vehicle efficient operation

Table 4: Operating costs in the basic and designed variants

Costs	Mileage, thousand km			
	50	100	150	200
Drivers salary with deductions, rubles/year	12,831.21	12,831.21	12,831.21	12,831.21
Fuel, rubles/year	4,286.92	4,286.92	4,286.92	4,286.92
Purchase and repair of tires, rubles/year	246.35	246.35	246.35	246.35
Maintenance and running repair, rubles/year	2,611.57	4,254.07	5,896.57	7,539.08
Rolling stock depreciation, rubles/year	1.383.52	1.383.52	1.383.52	1.383.52
Overheads, rubles/year	1,984.68	1,984.68	1,984.68	1,984.68
Total	23,344.25	24,986.75	26,629.25	28,271.76

Table 5: Economic indicators

Economic indicator,	Indicator value			
units of measurement	50	100	150	200
Income from transportation, thousand rubles/year	28,743.75	28,743.75	28,743.75	28,743.75
Profit, thousand rubles/year	5,399.5	3,757.0	2,114.5	471.99
Profitability of transportation,%	23.1	15.0	7.9	1.7

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