



THE DETERMINATION OF A COMPLEX CRITERION FOR ASSESSING THE PERFORMANCE OF TRACTION ROLLING STOCKS

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Abstract. For assessing the quality of rolling stocks, the research was made into the operational expenses aimed to derive their relation with the time of rolling stock operation which could be used as a basis of the above generalized complex criterion. In this way a dimensionless composite index with the value not exceeding one was obtained for assessing the locomotive performance. If this index is more than one, the rolling stock should be written off as inefficient and obsolete equipment.

Keywords: locomotive, diesel trains, rolling stocks.

1. Introduction

In order to essentially renew a traction rolling stock, a complex criterion allowing us to decide upon the replacement of old locomotives with the new ones should be established. To obtain this, the following issues should be taken into account: fuel consumption, the consumption of other materials (i.e. oil, fuel oil, etc.) needed for proper maintenance, idle time due to unscheduled repairs, frequency of failures, etc [1]. The above factors help us to assess the performance of a rolling stock from various perspectives. To assess the performance of rolling stocks from the above perspective, a complex criterion should be developed. For this purpose the research was made into the operational expenses aimed to derive their relation with the time of rolling stock operation which could be used as a basis of the above generalized complex criterion. In this way a dimensionless composite index with the value not exceeding one was obtained for assessing the locomotive performance. If this index is more than one, the rolling stock should be written off as inefficient and obsolete equipment.

2. Fuel consumption

Fuel consumption depends on many factors (i.e. mass of the train, locomotive speed, axle load, chassis design, etc.). However, for rolling stocks operating un-

der similar conditions, the above characteristics are practically the same. Therefore, fuel consumption may be considered one of the major factors indicating the performance of a rolling stock. Fuel consumption is commonly expressed as a relative value representing the amount of fuel used per 1000 km or 10 thous. km [2]. This value will be referred to as relative fuel consumption. The problem of the relation between relative fuel consumption and the rolling stock service life will be considered. Five 2M62 and six TEP60 locomotives as well as five DR1A diesel trains were tested. The statistical data of the years 2000–2002 were analyzed. Based on the available data, relative fuel consumption was determined for each rolling stock. The relation between the relative fuel consumption of locomotives 2M62 and TEP60 and their service life are given in Figs 1, 2.

As one can see in Fig 1, a period about 22 years may be considered the critical service life of locomotive 2M62, because relative fuel consumption starts to increase at this point. This may be accounted for consider-

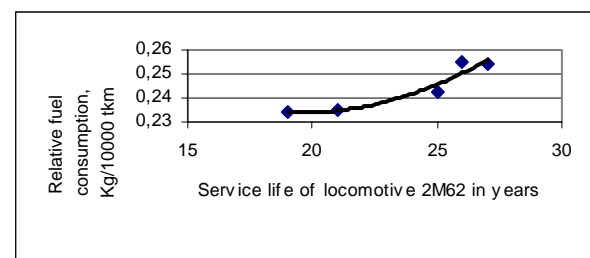


Fig 1. The relation between relative fuel consumption and service life of locomotives 2M62

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able deterioration of the locomotive engine and other units. Mathematically, the relation between relative fuel consumption and the locomotive service life may be expressed as a quadratic relation:

$$d_{2M62} = 0,0042 \cdot x^2 - 0,164 \cdot x + 3,9605, \quad (1)$$

here x – locomotive service life, in years;

d – relative fuel consumption, kg/10 thous. tkm (index 2M62 refers to a series of the locomotive).

For the locomotive service an life interval from in the 19 to 27 years 80 % of experimental data values are solution interval ± 2 % of the described equation (1).

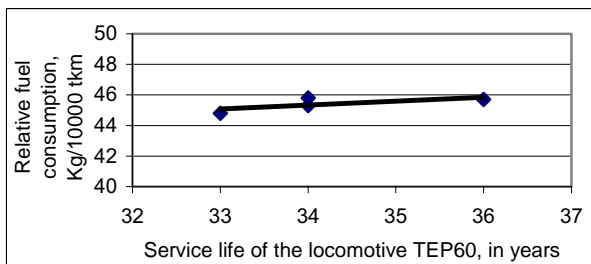


Fig 2. The relation between relative fuel consumption and service life of locomotives TEP60

One can not see a sudden change of the relative fuel consumption relation in the graph (Fig 2) as can be observed in Fig 1. This is because in this case the locomotives with service life exceeding normal service life by 1,5 and more times are investigated. This means that they are far beyond the critical point at which intense deterioration commences. However, the determined fuel consumption dependence on the locomotive service life allows us to assess qualitative changes of this indicator depending on the locomotive service life. In terms of mathematical expression this dependence is close to a linear relation:

$$d_{TEP-60} = 0,687 \cdot x + 21,46. \quad (2)$$

80 % of experimental data values for TEP60 locomotives with the service life ranging from 33 to 36 years are in the solution interval ± 2 % of the equation described (2).

The variation of relative fuel consumption of diesel locomotives DR1A is illustrated in Fig 3.

The diagram shows that relative fuel consumption of DR1A locomotives uniformly increases with the increase of their service life. Their service life ranges from 12 to 15 years, therefore they have not yet reached the time when sharp increase of fuel consumption begins (unlike TEP60 locomotives). In this case the variation of relative fuel consumption may be expressed by the following equation:

$$d_{DR1A} = 0,005 \cdot x^2 - 0,025 \cdot x + 51,92. \quad (3)$$

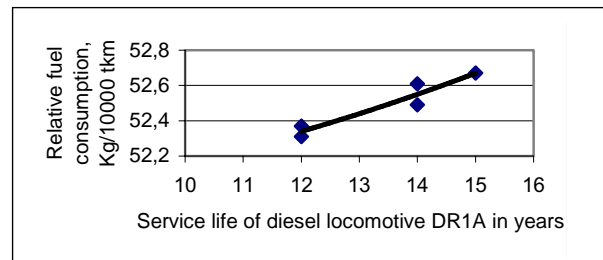


Fig 3. The variation of relative fuel consumption of diesel locomotives DR1A

For the service life interval from 12 to 15 years 80 % of the experimental data values are in the solution interval $\pm 0,2$ % of the equation described (3).

3. Oil consumption

Traction rolling stocks consume fuel, but they also use other materials, such as rubber, plastics, thick oil, engine oil, etc. The type of rolling stock determines the consumption of engine oil. Engine oil is not a source of power, therefore, the increase of engine oil consumption indicates poor performance of an engine or other units. Engine oil consumption will be described depending on the locomotive service life as it was previously done for fuel consumption. The relations between engine oil consumption and the service life of rolling stocks with the locomotives 2M62 and TEP60 are given in Fig 4 and Fig 5.

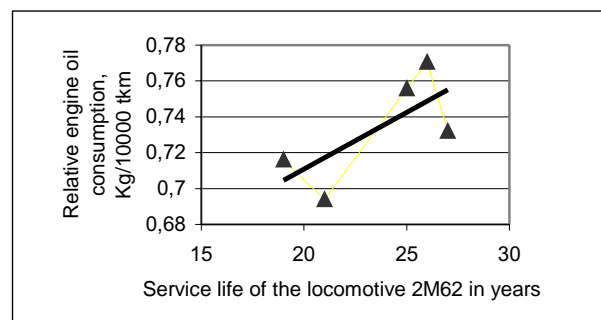


Fig 4. The relation between relative engine oil consumption and service life of locomotives 2M62

From Fig 4 we can see that a mathematical relation given there is not so rigorous as, for example, a relation presented in Fig 1. It is expressed by a straight line:

$$a_{2M62} = 0,00631 \cdot x + 0,5846, \quad (4)$$

here a – relative engine oil consumption, kg/10 thous. tkm.

In the graph we can see two points which are rather far from this line (these are the locomotives with the service life ranging from 21 to 27 years). The above spread in

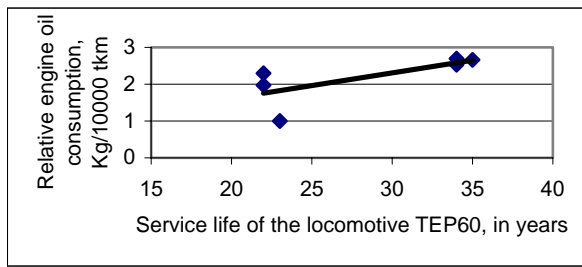


Fig 5. The variation of relative engine oil consumption of locomotives TEP60

values does not mean that the data were not properly collected or that there were some errors in mathematical analysis, because it could be influenced by some other factors (i.e. distance run between overhauls, traction rolling stock mass, etc.). These factors usually do not have the qualitative effect on the relation, causing, however, the above spread in values. For the service life from 19 to 27 years, 80 % of the experimental data values are in the solution interval of the described equation (4) ± 3,5 %.

Mathematical expression of the relation between engine oil consumption by TEP60 locomotives is as follows:

$$a_{TEP-60} = 0,069 \cdot x + 0,238. \tag{5}$$

For locomotives TEP60 with the service life interval from 33 to 36 years, 85 % of the experimental data values are in the solution interval ± 2 % of the described equation (5).

The comparison of the data given in Figs 4,5 demonstrates that the linear increase of relative engine oil consumption can be observed according to the increase of the locomotives service life, while the straight line direction coefficient is of the same range (0,00631 and 0,0069) in both cases.

The variation of relative oil consumption of diesel locomotives DR1A in time is shown in Fig 6.

Engine oil consumption of DR1A diesel locomotives depending on their service life varies according to the following relation:

$$a_{DR1A} = 0,0147 \cdot x + 1,745. \tag{6}$$

Transmission oil consumption of DR1A diesel locomotives depending on their service life varies according to this relation:

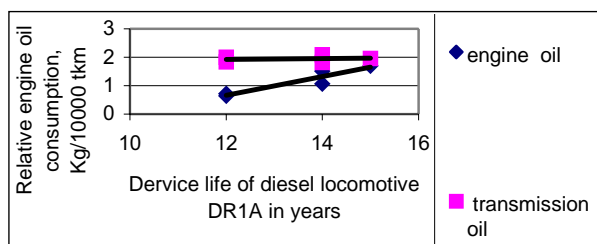


Fig 6. The variation of relative consumption of engine and transmission oil by diesel locomotives

$$a_t = 0,3275 \cdot x + 3,262, \tag{7}$$

here a_t – relative transmission oil consumption, kg/10 thous. tkm.

In the service life interval of 19 – 27 years, 80 % of the experimental data values obtained for DR1A locomotives are in the solution interval ± 2 % of the described equations (6), (7).

4. The analysis of repair costs

The costs of maintenance and repairs may be described in terms of idle time due to failures [3, 4]. This technique was used because of easy calculation and manipulation with the available data. On the other hand, the problem of correctness of the above approach arises. The statistical data show that the idle time (in hours) of rolling stocks is proportional to the expenses. This implies that if we consider the relation between the locomotive idle time and its service life it would be equivalent to the analogous relation of expenses. The relations between relative traction rolling stock idle time and their service life are given in Figs 7–9.

By approximating the relation given in Fig 7 we get a regression equation:

$$p_{2M62} = 0,00219 \cdot x + 0,02177, \tag{8}$$

here p – relative idle time, h/10 thous. tkm.

By approximating the relation given in Fig 8 we get a regression equation:

$$p_{TEP-60} = 0,0035 \cdot x - 0,067. \tag{9}$$

In Figs 7, 8 we can observe the linear dependence of the idle time increase of 2M62 and TEP60 locomotives on their service life, though the straight line coefficient of TEP60 locomotives is by about 5,5 times lower. This allows us to conclude that the number of failures of TEP60 locomotives is less dependent on their service life than that of 2M62 locomotives. It may be accounted for the fact that TEP60 are passenger locomotives operating under more favorable conditions (smaller rolling stock mass), therefore, they are not so prone to failures.

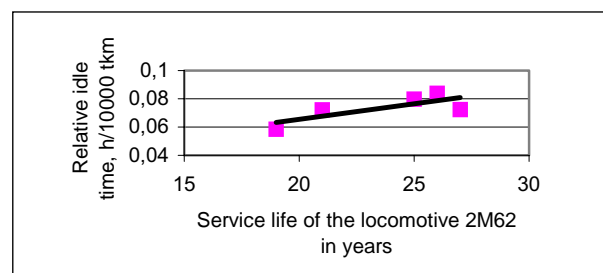


Fig 7. The dependence of relative idle time of locomotives 2M62 on their service life

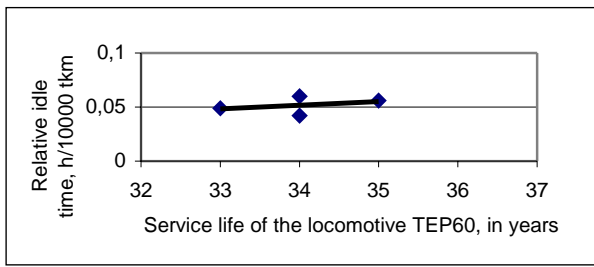


Fig 8. The dependence of relative idle time of the locomotives TEP60 on their service life

By approximating the relation given in Fig 9, we get an equation:

$$p_{DR1A} = 0,0329 \cdot x + 0,243. \quad (10)$$

80 % of the experimental data values are found in the solution interval $\pm 2\%$ of the described equations (8), (9), (10).

Generalizing the statistical data obtained we can state that:

- relative fuel consumption of the locomotives 2M62 increases according to a quadratic relation (1);
- consumption of other kinds of fuels in other types of locomotives increase according to linear relations (2)–(7);
- consumption of the transmission oil by DR1A diesel locomotives is growing particularly fast (by 3,5 times per 2 years). This means that in further operation special attention should be paid to their transmission (hydraulic drives);
- based on the derived relations describing the consumption of various maintenance and operational materials, we may obtain a complex criterion for accessing the performance of traction rolling stocks.

5. The formation of a composite index to assess the performance of traction rolling stocks

A composite performance assessing index of traction rolling stocks presented here can be used to determine the costs of fuels, oils and unscheduled repairs. Its structure is as follows:

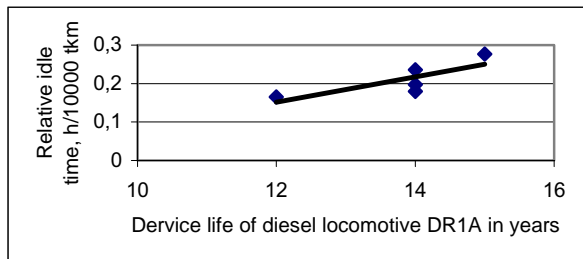


Fig 9. The dependence of relative idle time of diesel locomotives DR1A on their service life

$$K = d \cdot I_d + a \cdot I_a + r \cdot I_r, \quad (11)$$

here K – composite performance assessing index of traction rolling stocks, Lt/10 thous. tkm;

d – relative fuel consumption, kg/10 thous. tkm;

a – relative oil consumption, kg/10 thous. tkm;

r – relative costs of unscheduled repairs, h/10 thous. tkm;

I_d – costs per unit fuel, Lt/kg;

I_a – costs per unit oil mass, Lt/kg;

I_r – costs of a conditional unit of unscheduled repairs.

We will derive the expressions for a composite index K for each rolling stock based on the formula (11) by substituting formulas (1)–(10) into it.

The index K_{2M62} of locomotives 2M62 will be expressed in the following way K_{2M62} :

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$$K_{2M62} = (0,042 \cdot x^2 - 1,64 \cdot x + 39,6) \cdot I_d + (0,00631 \cdot x + 0,5846) \cdot I_a + (0,00219x + 0,02177) \cdot I_p, \quad (12)$$

here x – rolling stock service life, years

The index K_{TEP60} of the locomotives TEP60 will be expressed as follows:

$$K_{TEP60} = (0,687 \cdot x + 21,46) \cdot I_d + (0,069 \cdot x + 0,238) \cdot I_a + (0,0035 \cdot x - 0,0672) \cdot I_p. \quad (13)$$

The index K_{DR1A} for diesel locomotive DR1A will be of the form:

$$K_{DR1A} = (0,005 \cdot x^2 - 0,025 \cdot x + 51,92) \cdot I_d + (0,0147 \cdot x + 1,745) \cdot I_a + (0,00329 \cdot x + 0,243) \cdot I_p. \quad (14)$$

6. Graphical representation of the dependence of a composite rolling stock performance index on the locomotive service life

Based on the formulas (12), (13), (14) as well as on the cost of engine oil and repairs in 2003 (which are 1.69 Lt/kg, 0,869 Lt/kg and 26,07 Lt/h, respectively) graphs showing the dependence of composite rolling stock performance indices on their service life are plotted.

The dependence of a composite performance index of locomotives 2M62 on their service life is shown in Fig 10.

The relation given in Fig 10 is described by equation:

$$K_{2M62} = 0,071 \cdot x^2 - 2,709 \cdot x + 68. \quad (15)$$

The dependence of a composite performance index of locomotives TEP60 on their service life is shown in Fig 11.

The relation given in Fig 11 is described by the equation:

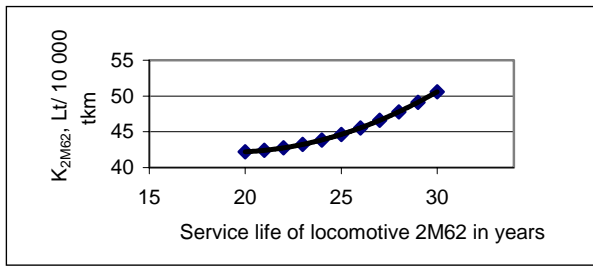


Fig 10. The relation between the composite performance index of the locomotives 2M62 and their service life

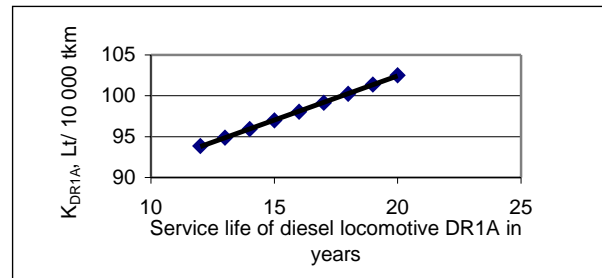


Fig 12. The relation between the composite performance index of the diesel locomotive DR1A and its service life

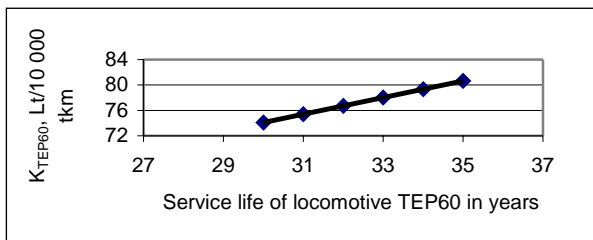


Fig 11. The relation between the composite performance index of locomotives TEP60 and their service life

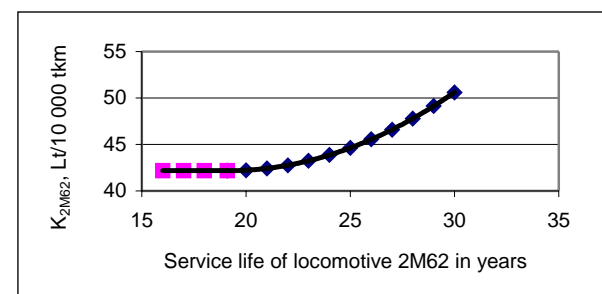


Fig 13. The relation of index K_{2M62} with a sudden change point

$$K_{TEP60} = 1,312 \cdot x + 34,72. \quad (16)$$

The dependence of a composite performance index of diesel locomotives DR1A on their service life is demonstrated in Fig 12.

The relation given in Fig 12 is described by the equation:

$$K_{DR1A} = 1,08 \cdot x + 80,82. \quad (17)$$

Since the assignment is to find a point where a sharp increase of a composite traction rolling stock performance index originally occurs, let us do a mathematical analysis of the graphs presented in Figs 12–14.

The dependence of a composite performance index of locomotives 2M62 on their service life is described by a quadratic equation (11). The point at which a sharp increase originally occurs will be that where a derivative of the quadratic equation is equal to zero. A derivative of the equation (11) is described by the following equation:

$$K'_{2M62} = 0,142 \cdot x - 2,71. \quad (18)$$

In Fig 13 one can see that index K_{2M62} of the locomotives 2M62 with the service life up to 19 years is about 42 Lt/10 000 tkm, while for the service life over 20 years it starts to increase according to a quadratic relation.

The dependence of a composite performance index of locomotives TEP60 on their service life is described by the linear equation (16). This equation may describe the locomotives of 30–35 years of service. In this range, the point of sharp increase of the index K_{TEP60} has already been passed. Basing ourselves on the equation (11) we

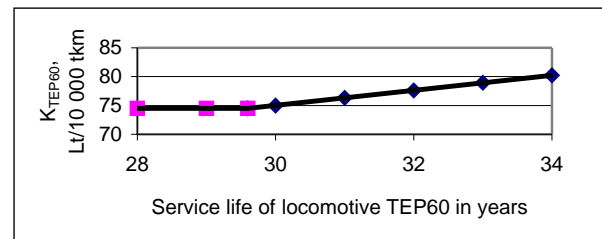


Fig 14. The relation of index K_{TEP60} with a sudden change point

will calculate the index K_{TEP60} for 12–13 year old TEP60 locomotives. It is equal to 74,5 Lt/10 000 tkm. This is the ordinate of a sudden change point of the graph representing the dependence of index K_{TEP60} on the locomotive service life. Basing ourselves on the equation (12), we will calculate the abscissa of the above point. It is $x = 29,6$ years.

The relation of the index K_{TEP60} with a sudden change point is demonstrated in Fig 14.

Fig 14 shows that the index K_{TEP60} of the locomotives TEP60 up to 30 years of service is about 74.5 Lt/10000 tkm, while when their service life is over 30 years the above index starts growing.

7. The development of non-dimensional indices for assessing rolling stock performance

Indices for assessing rolling stock performance should be non-dimensional in order to be used indepen-

dently of indices used for quantitative financial evaluation of the locomotive operation. The above index is assumed to be equal to one at the point of a sudden change. Then, a composite index for assessing the performance feature of rolling stocks with respect to their service life will be described by the following equation:

$$k_{2M62} = 0,00169 \cdot x^2 - 0,0645 \cdot x + 1,619; \quad (19)$$

$$k_{TEP60} = 0,0176 \cdot x + 0,466. \quad (20)$$

The dependence of the model described by the equations (19), (20) is demonstrated in Figs 15, 16.

There, one can see the relations demonstrated in Figs 13, 14 which are adapted to be used independently of operational costs dimension.

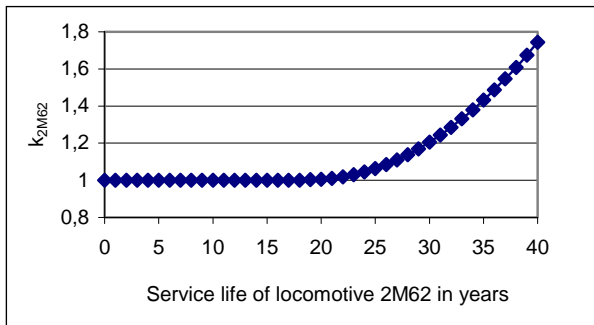


Fig 15. The relation between non-dimensional index k_{2M62} and service life of the locomotive

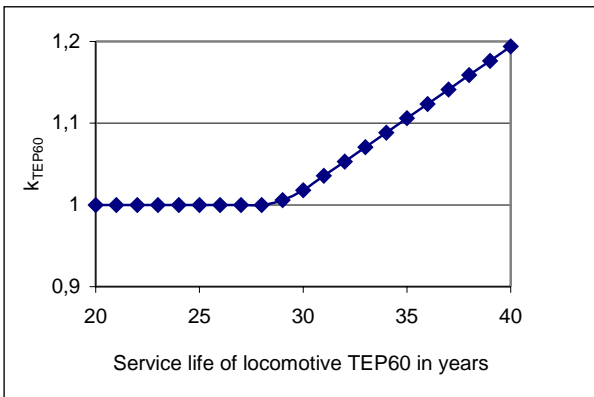


Fig 16. The relation between non-dimensional index k_{TEP60} and service life of the locomotive

8. Conclusions

1. According to the current prices of maintenance materials and repairs (see Section 5), locomotives 2M62 should be used when the index K_{2M62} is not higher than 42 Lt/10 thous. tkm, which means that their service does not exceed 19 years. When locomotives have been in service for more than 19 years, the above index begins to increase according to a quadratic relation.

2. Locomotives TEP60 should be used until the index K_{TEP60} is lower than 74,5 Lt/10 thous. tkm, which means that their service life is less than 29 years. Later the expenses begin to rise sharply.

3. The following universal non-dimensional indices for the locomotives have been determined: $K_{2M62} = 1,0$, corresponding to the locomotive service life not exceeding 19 years, or to 2,0 m total kilometers logged, with 10,5 thous. total kilometers logged per year, and $K_{TEP60} = 1,0$, corresponding to the locomotive service life not exceeding 29 years, or to 3,92 m total kilometers logged, with 134 thous. total kilometers logged per year.

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