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DETERMINING THE EFFICIENT SERVICE LIFE OF TRACTION ROLLING STOCKS

To maintain and renew traction rolling stocks, the causes of their deterioration which are closely connected with operational conditions should be identified. For this purpose, such parameters of rolling stocks as the performed work, speed, acceleration, mass, etc. should be properly determined. The first objective is to develop mathematical models to evaluate integrated criteria describing the deterioration of freight and passenger locomotives from technical and economical perspectives. The second goal is to compare the main criteria describing the process of deterioration of freight and passenger locomotives and the respective differences in the strategies of their renewal. Fuel consumption, engine oil consumption and terminal delays due to off-schedule locomotive maintenance were investigated. Each of these parameters may be used to determine the locomotive state (quality) from a particular perspective.

***Keywords**: Traction rolling stocks, locomotives, fuel consumption*

1. Introduction

To maintain and renew traction rolling stocks, the causes of their deterioration which are closely connected with operational conditions should be identified. For this purpose, such parameters of rolling stocks as the performed work, speed, acceleration, mass, etc. should be properly determined. As shown by testing, rolling stock mass has a great effect on the rate of its deterioration [1]. Masses determine loads applied to the major units of locomotives (e.g. engine power or revolutions per minute, brake operation, loads acting on the suspension). Because of various rolling stock masses (which may differ tenfold) the operational conditions of freight and passenger locomotives differ considerably. This allows us to assume that their deterioration has some specific features as well, implying that the management of their parks and the renewal strategy should also differ. These strategies should be developed taking into account the deterioration peculiarities of freight and passenger locomotives.

1.1. Goals and objectives of the research

The first objective is to develop mathematical models to evaluate integrated criteria describing the deterioration of freight and passenger locomotives from technical and economical perspectives. These criteria may be used for determining if the particular locomotives could be further employed. The second goal is to compare the main criteria describing the process of deterioration of freight and passenger locomotives and the respective differences in the strategies of their renewal.

1.2. Research methods

Fuel consumption, engine oil consumption and terminal delays due to off-schedule locomotive maintenance were investigated. Each of these parameters may be used to determine the locomotive state (quality) from a particular perspective. For describing the locomotives from various perspectives, a special qualitative criterion relating to the above-mentioned aspects should be developed. For this purpose, mathematical relationships between fuel consumption and the age of the locomotives were established. They were used as a basis for developing this integrated criterion. In this way, an integrated dimensionless qualitative criterion, with the value not exceeding the unity, which could be used for describing the locomotives, was obtained. If the value of the above criterion for a particular locomotive is more than unity, this locomotive should not be further employed.

2. Investigating fuel consumption

Fuel consumption is a basic qualitative characteristic of locomotives [2]. Usually, fuel consumption is expressed as a relative value, i.e. the amount of fuel consumed per 1000 or 10000 tkm (relative fuel consumption). The relationship between relative fuel consumption and the age of passenger and freight locomotives is analysed. Five freight and six passenger locomotives are tested. The engine power of freight locomotives reaches 2940 kW, the mass is about 238 ton and the highest speed is 100km/h, while the engine power of passenger locomotives ranges from 2205 to 2940 kW, the mass is about 128 ton and the highest speed is 160 km/h.. The relationships between relative fuel consumption of the considered locomotives and their age based on the available statistical data are shown in Fig 1.

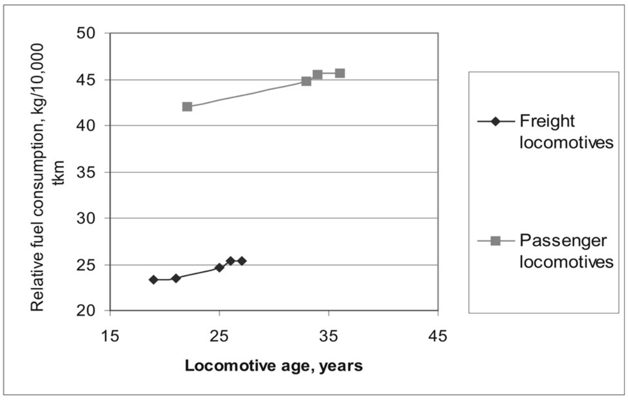

Fig 1. The relationship between relative fuel consumption of the locomotives and their age

As shown by the graphs in Fig 1, the critical age for freight locomotives is around 22 years because at this point fuel consumption starts growing. This may be accounted for by considerable wearing of the locomotive's engine and other units. By approximating the relationship between relative fuel consumption and the locomotive age with the help of the least square method, it was expressed as a quadratic equation:

$$d_H = 0.0042 \cdot x^2 - 0.164 \cdot x + 3.9605 \quad (1)$$

where: x – is the locomotive age, years; d – is relative fuel consumption, kg/ 10,000 tkm (H means a freight locomotive, while P stands for a passenger locomotive).

For the locomotives with the age ranging from 19 to 27 years, about 80 % of experimental data may be described by equation (1) within the interval of solution making ±2%.

In mathematical terms, the relationship between relative fuel consumption and the passenger locomotive age may be expressed as a linear equation:

$$d_P = 0.687 \cdot x + 21.46 \quad (2)$$

On approximation, about 80% of experimental data on passenger locomotives fit within the solution interval of ±2% of the above equation (2).

3. The analysis of oil consumption

In addition to fuel consumption, many other materials, such as rubber, plastics, thick and engine oil, are used in locomotives. Engine oil consumption largely depends on the locomotive state. Engine oil is not a source of power, therefore, the increased consumption indicates a poor state of the locomotive engine or other units. Engine oil consumption will be compared for the locomotives of various age as it was done in investigating fuel consumption. The relationship between relative engine oil consumption and the locomotive age is shown in Fig 2.

As shown by the graphs in the above figure depicting engine oil consumption in freight as well as passenger locomotives, the relationship analysed is described in mathematical terms as a straight line. For the freight locomotives it is expressed as follows:

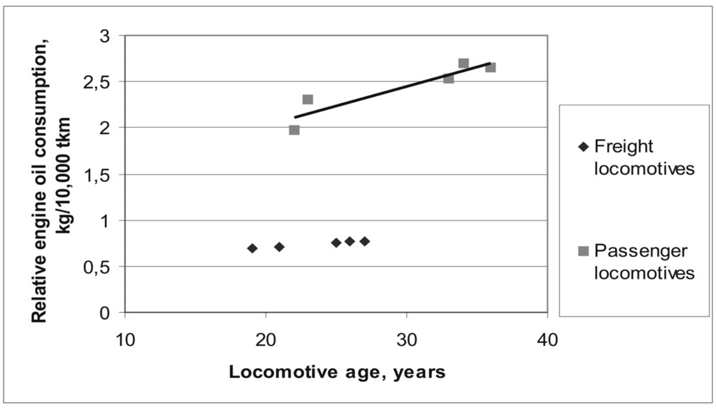

Fig 2. The relationship between relative engine oil consumption of the locomotives and their age

$$a_H = 0.00631 \cdot x + 0.5846 \qquad (3)$$

where: a – relative engine oil consumption, kg/10,000 tkm.

It may be observed that, in addition to the locomotive age, some other factors (e.g. the run of the locomotive, overhaul standards, mass of traction rolling stocks, etc.) may influence the results. These parameters usually do not affect the relationship qualitatively, but may cause the spread of experimental data values. Within the range of 19-27 years of service, 80 % of experimental data values were found to be in the solution interval of ±3.5% of equation (3).

A mathematical relationship between relative engine oil consumption and passenger locomotive age is as follows:

$$a_P = 0.069 \cdot x + 0.238 \qquad (4)$$

Approximately 85 % of experimental data values obtained for passenger locomotives were found to be in the solution interval of ±2% of the equation (4).

The line direction coefficients of passenger and freight locomotive fuel consumption are of the same order (0.00631 and 0.0069).

4. The analysis of repair costs

Maintenance and repair costs may be determined in terms of the time of terminal delays due to failures (in hours). This method is chosen because the delay hours can be easily calculated and the obtained data are easily handled. Another problem concerns the accuracy of this assessment technique. Statistical data show that terminal delays of locomotives (in hours) are proportional to their costs. This means that, if we consider the relationship between the delay (idle) time and the locomotive age, it will correlate with the respective cost relationship. The relationships between relative terminal delays and the locomotive age are presented in Fig 3.

By approximating [3] the relationship of relative freight locomotive terminal delays in Fig 3 we will get the following regression equation:

$$p_H = 0.00219 \cdot x + 0.02177 \qquad (5)$$

where: p – relative terminal delay, h/10,000 tkm.

Terminal delays for passenger locomotives will be expressed by the following regression equation:

$$p_P = 0.0035 \cdot x - 0.067 \qquad (6)$$

The graphs in Fig 3 show that relative terminal delay time of freight and passenger locomotives is linearly increasing with the increase of locomotive age, however the coefficient of line direction is by 5.5 times lower for passenger locomotives. Therefore, it can be stated that the number of passenger locomotive failures is less dependent on their age than it is for freight locomotives. It may be accounted for by the fact that the conditions of operation for passenger locomotives are better (rolling stock mass is smaller). Therefore, the number of passenger locomotive failures grows slower than in freight locomotives.

Based on the analysis of the obtained statistical data, it may be stated that:

1. relative fuel consumption of freight locomotives increases according to a quadratic equation (1);
2. the consumption of other maintenance materials increases according to linear equations (2)-(6) for all locomotives;
3. given the relationships describing the consumption of maintenance materials for rolling stocks, it is possible to generate integrated criteria to assess their quality and to compare them.

5. Generating integrated qualitative criteria describing the locomotives

The following qualitative integrated criterion is used to determine fuel and oil consumption as well as the repair costs of the locomotives. It is expressed as:

$$K = d \cdot I_d + a \cdot I_a + r \cdot I_r \qquad (7)$$

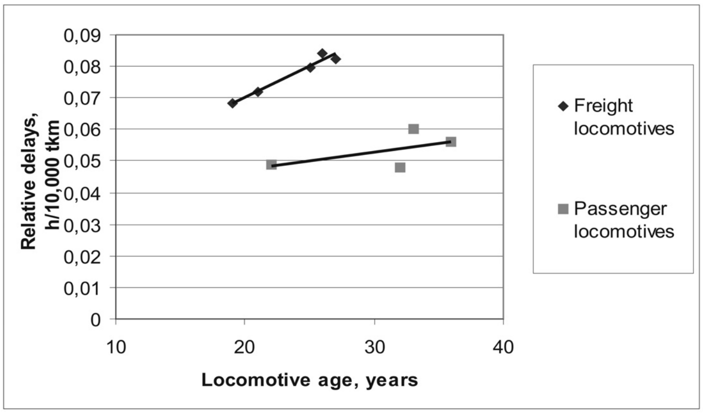

Fig 3. The relationship between relative delays of locomotives and their age

where: K – integrated qualitative locomotive criterion, Eur/10,000 tkm; d – relative fuel consumption, kg/10,000 tkm; a – relative oil consumption, kg/10,000 tkm; r – relative time of off-schedule repairs, h/10,000 tkm; I_d – costs of fuel per unit of quantity, Eur/kg; I_a – costs of oil per unit of mass, Eur/kg; I_r – costs of off-schedules repairs, per unit, Eur/h.

An integrated criterion K may be expressed for every locomotive by the formula (7), with the formulas (1) – (6) substituted into it.

For freight locomotives, an integrated criterion K_H will be of the form:

$$\begin{aligned} K_H &= (0.042 \cdot x^2 - 1.64 \cdot x + 39.6) \cdot I_d + \\ &+ (0.00631 \cdot x + 0.5846) \cdot I_a + \\ &+ (0.00219x + 0.02177) \cdot I_p \end{aligned} \tag{8}$$

where: x – is the locomotive age, years.

For passenger locomotives the expression of the criterion K_P will be as follows:

$$\begin{aligned} K_P &= (0.687 \cdot x + 21.46) \cdot I_d + \\ &+ (0.069 \cdot x + 0.238) \cdot I_a + \\ &+ (0.0035 \cdot x - 0.0672) \cdot I_p \end{aligned} \tag{9}$$

6. Graphical representation of the relationship between a qualitative integrated criterion and the locomotive age

Based on the formulas (8) and (9) as well as the costs of fuel, engine oil and repairs (which currently make 0.483 Eur/kg and 0.248 Eur/kg, respectively, in Lithuania), the graphs representing the relationships between integrated qualitative locomotive criteria and the locomotive age are plotted.

The relationship between the integrated qualitative locomotive criterion and the locomotive age is given in Fig 4.

It may be expressed by the following equation:

$$K_H = 0.00585 \cdot x^2 - 0.225 \cdot x + 12.765 \tag{10}$$

The integrated qualitative criterion relating to passenger locomotives may be described by the equation:

$$K_P = 0.3897 \cdot x + 9.4615 \tag{11}$$

Since the point of the beginning of sharp increase of the integrated criterion value should be determined, a mathematical analysis (10), (11) of the graphs presented above should be made.

The relationship between the integrated qualitative criterion and passenger locomotive age may be described by a quadratic equation (10). The point at which the criterion value begins to rise sharply will be that at which the derivative of the quadratic equation is equal to zero. The derivative of the equation (10) is expressed as follows:

$$K'_H = 0.0117 \cdot x - 0.225 \tag{12}$$

Based on the equation (11), the criterion K_P relating to passenger locomotives with service life of 12-13 years can be calculated. It will be equal to 21.3 Eur/10,000 tkm. It is the ordinate of the graph's break point for the criterion K_P relationship with the locomotive age. Let us calculate the abscissa of this point based on the equation (12). It is ***x*=<u>29.6</u>** years. The relationships relating to the criteria $\boldsymbol{K_H}$ and $\boldsymbol{K_P}$ with the break points of the graphs are presented in Fig.5.

Fig 5 shows that the average value of K_H for freight locomotives of up to 19 years of service life is about 12 Eur/10,000 tkm, while after 20 years of service it begins to grow according to the quadratic equation. For freight locomotives of about 30 years of service the value of the criterion K_P is approximately equal to 21.3 Eur/10,000 tkm, while when this age is exceeded, this value begins to grow.

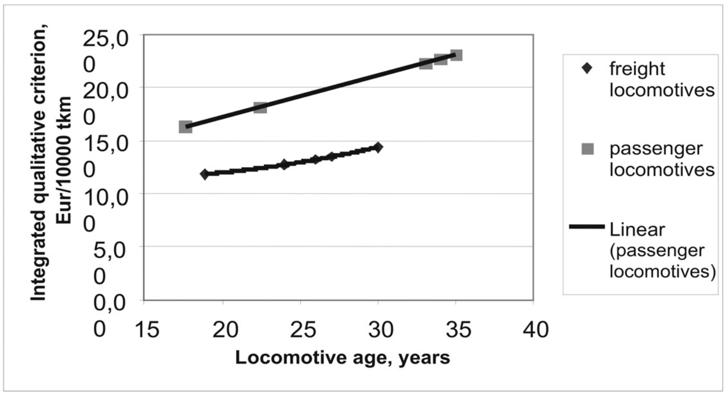

Fig 4. The relationship between the integrated qualitative criterion of the locomotive and its age

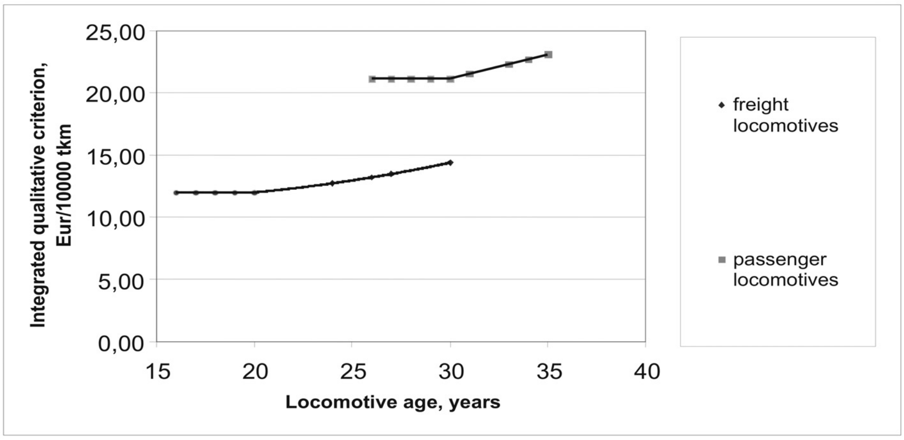

Fig 5. The relationships of K_H and K_P with the break points

7. Generating the dimensionless criteria

In order to apply qualitative criteria of the locomotives independently of their quantitative criteria describing the financial aspects related to maintenance costs of the locomotives, the former should be dimensionless. The value of the qualitative criterion at the break point is assumed to be equal to unity. Then, the integrated qualitative criterion of the locomotives depending on their age is described by the following equations:

$$k_H = 0.00169 \cdot x^2 - 0.0645 \cdot x + 1.619 \quad (13)$$

$$k_P = 0.0176 \cdot x + 0.466 \quad (14)$$

The relationship of the model described by the equations (13) and (14) is presented in Fig 6.

The relationships presented in Fig 6 can be used independently of the dimensions relating to maintenance costs. It can be observed that the guaranteed life of passenger locomotives expressed in years is 1.5 times that of freight locomotives. This may be accounted for by better maintenance conditions and use of passenger locomotives.

8. Conclusions

1. Taking into account the current prices of the locomotive oil and other maintenance materials as well as the repair costs in Lithuania, freight locomotives should be used until the value of the criterion K_H is not higher than 12 Eur/10,000 tkm, i.e. their service life should be equal to 19 years. When this age is reached, the value begins to increase according to a quadratic equation.
2. Passenger locomotives should be employed until the value of the criterion K_P is not higher than 21.3 Eur/10,000 tkm, which corresponds to 29 years of service life. When this age is reached, the costs start to increase considerably.
3. The dimensionless criteria for the locomotives are: $K_H \leq 1.0$, when the locomotive service life is not more than 19 years or the run is about 2 mln km and the average annual run – 105 thous. km; and $K_P \leq 1.0$, when passenger locomotive service life is not more than 29 years, or the run is 3.92 mln km, with the average annual run of 135 thous. km.
4. The guaranteed life of passenger locomotives expressed in years is 1.5 times that of freight locomotives.

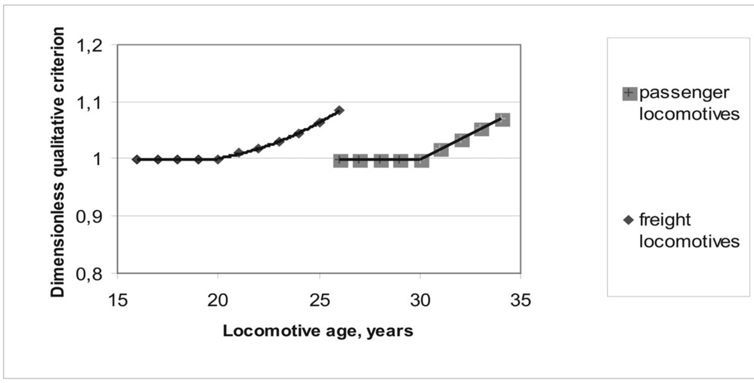

Fig 6. Dimensionless qualitative criteria of the locomotives

9. References

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