

Correction of engineering servicing regularity of transport-technological machines in operational process

A N Makarova, E I Makarov, N S Zakharov

Industrial University of Tyumen, 38, Volodarskogo St., Tyumen, 625000, Russia

E-mail: Makarova-a-n@mail.ru

Abstract. In the article, the issue of correcting engineering servicing regularity on the basis of actual dependability data of cars in operation is considered. The purpose of the conducted research is to increase dependability of transport-technological machines by correcting engineering servicing regularity. The subject of the research is the mechanism of engineering servicing regularity influence on reliability measure. On the basis of the analysis of researches carried out before, a method of nonparametric estimation of car failure measure according to actual time-to-failure data was chosen. A possibility of describing the failure measure dependence on engineering servicing regularity by various mathematical models is considered. It is proven that the exponential model is the most appropriate for that purpose. The obtained results can be used as a separate method of engineering servicing regularity correction with certain operational conditions taken into account, as well as for the technical-economical and economical-stochastic methods improvement. Thus, on the basis of the conducted researches, a method of engineering servicing regularity correction of transport-technological machines in the operational process was developed. The use of that method will allow decreasing the number of failures.

1. Introduction

When operating cars in conditions of the North and Siberia, the processes of operation and car technical state change have significant peculiarities [1].

On the whole, hard usage is typical but not considered in the current method of engineering servicing regularity correction [2]. To determine the engineering servicing regularity that provides a desired reliability measure, it is necessary to define the type and parameters of times to failure distribution law on the basis of a representative sample. But while carrying out preventive operations of engineering servicing, most potential failures are prevented, that is why only a truncated sample can be obtained. Determining accuracy of times to failure distribution parameters, with the use of the known methods of unfinished experiments processing, is not sufficient for standards determination and correction in those conditions.

In researches conducted earlier, a number of methods of determination and correction of engineering servicing regularity standards are developed, but all of them have assumptions and limitations that decrease calculation accuracy and limit the field of application.



The world's leading car manufacturers usually offer simple methods of correcting standards of engineering servicing regularity. For example, for Mercedes trucks going on long-haul trips, engineering servicing regularity is 100.000 km, but for trucks in hard usage, the standard may be reduced to 30.000 km. But it is not clear what exactly hard usage means and how much the standard should be reduced.

Thus, a topical problem of operational correction of regularity standards of car engineering servicing exists, and must be solved with specifics of operational conditions taken into account.

2. Research method

To develop a method of correction of engineering servicing regularity standards in that case, the task is formalized in the following way:

in the interval of operational times from $L=0$ to $L=L_{ES}$, m elements out of N failed;

times to failure are labelled as L_1, L_2, \dots, L_m ;

failure measure in the considered interval of times to failure is $F(L_{ES}) = \frac{m}{N}$;;

actual failure measure exceeds the allowed reliability measure set by maintenance system $F(L_{ES}) > F_v$;

it is required to determine the L_{ES} value at which $F(L_{ES}) = F_v$.

To solve the set task, failure measure must be calculated at points L_1, L_2, \dots, L_m of the considered interval:

$$F(L_1) = 1/N; F(L_2) = \frac{2}{N}; \dots; F(L_m) = m/N.$$

In general form, $F(L_i) = i/N$, where $i = 1 \dots m$.

Next, m pairs of values L_i and $F(L_i)$ are considered. They represent the influence of operational time on failure measure. These values are approximated by a regression equation. With the use of the equation, L_{ES} value at which $F(L_{ES}) = F_v$ is calculated.

A key moment in solving this task is choosing the type of a regression equation that adequately approximates the initial data.

A preliminary analysis of the graphical view of the considered function in the interval of $0 \dots L_{ES}$, its asymptotics and a possible model structure for m pairs of L_i and $F(L_i)$ values, allowed one to assume that an exponent or a polynomial can be used as a model:

$$F(L) = A_0 e^{A_1 L};$$

$$F(L) = A_0 + A_1 L + A_2 L^2,$$

where A_0, A_1, A_2 are empirical coefficients.

The advantage of these models is the possibility of receiving the first derivative in a general form, which is a differential distribution function; for example, for the exponential model:

$$f(L) = A_0 A_1 e^{A_1 L}.$$

To check that hypothesis and choose the most appropriate model among the listed, an experimental research was carried out.

3. Experimental research

That hypothesis was checked in imitation and experimental researches.

Samples of times to failure of car elements distributed according to various laws were generated.

The experiment was carried out for the most common distribution laws of times to failure which are normal, lognormal and Weibull's laws.

The received samples were processed: the basic statistics were calculated (average of distribution, dispersion, asymmetry and excess parameters); probability of adequacy to a chosen distribution law was estimated (using Pearson's criterion).

After that, empirical values of failure measure were calculated in the interval of $F_{emp}(L) = 0 \dots 0.2$. Pairs of L_i and $F_{emp,i}(L)$ values were approximated by an integral distribution, quadratic and exponential function. The model's adequacy was checked using Fisher's test and the standard approximation deviation.

To estimate adequacy with Fisher's test, $D_{res.}/D_{F_{emp.}}$, variance ratio was calculated and compared to the table value for a certain confidence probability.

While counting the standard approximation, deviation problems may occur because in the used formula:

$$\bar{\varepsilon} = \frac{1}{N} \sum_{i=1}^N \frac{|F_{emp.} - F_t|}{F_{emp.}} 100\%$$

denominator $F_{emp.}$ can be close to zero, while F_t can be twice as much. As a result, $\bar{\varepsilon}$ value will exceed the valid value. For example, if $F_{emp.}=0.01$, and $F_t=0.02$, deviation in that point will be 100 %. Given that maintenance system is not estimated by failure measure, but by reliability measure, to estimate the model's accuracy it is rational to change failure measure to reliability measure in the previous formula:

$$\bar{\varepsilon} = \frac{1}{N} \sum_{i=1}^N \frac{|R_{emp.} - R_t|}{R_{emp.}} 100\%.$$

Besides, standard approximation deviation is not sufficient to characterize a model. It is important to know the model's accuracy level at the key points, which are reliability measure 0.90 and 0.95 (engineering servicing regularity is determined according to these values). For that reason, at the experiment processing two more model's adequacy indicators, $\varepsilon_{0.90}$ and $\varepsilon_{0.95}$, were calculated:

$$\varepsilon_{0.95} = \frac{|0.95 - R_t^{(0.95)}|}{0.95} 100\%; \quad \varepsilon_{0.90} = \frac{|0.90 - R_t^{(0.90)}|}{0.90} 100\%.$$

To analyze the experiment results, average and extreme values of adequacy indicators are calculated.

4. Results

Imitation experiments were conducted to check the hypothesis about the model type of engineering servicing regularity influence on reliability measure of car operation in the conditions of most failures prevention. For that purpose, samples of times to failure of car elements were generated, being distributed according to normal, exponential and Weibull's law (16 samples on the whole). The samples were processed. After that, empirical values of failure measure were calculated in the interval of $F(L) = 0 \dots 0.2$. L_i and $F(L_i)$ value pairs were approximated by accumulated distribution, a quadratic and exponential model. Results fragments are presented in fig. 1 ... 4.

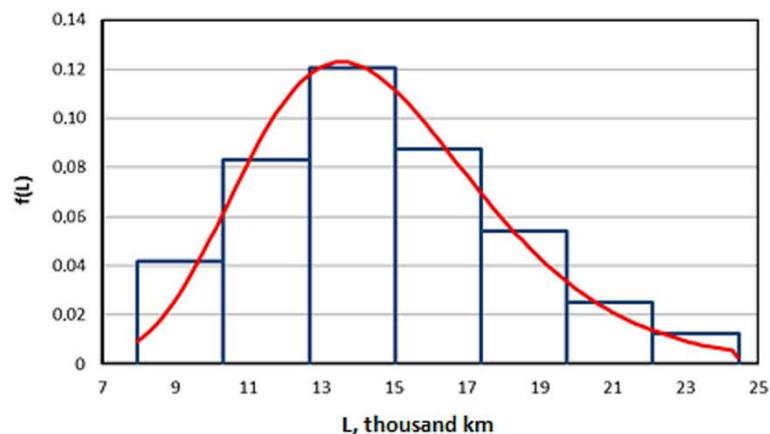


Figure 1. Times to failure distribution (lognormal law)

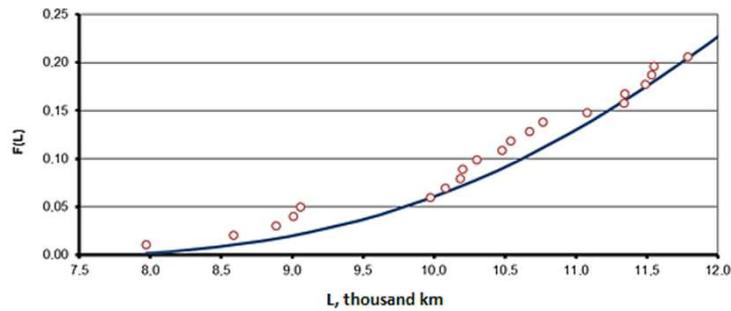


Figure 2. Approximation of empirical values of failure measure by lognormal law in the interval of $F(L) = 0 \dots 0.2$

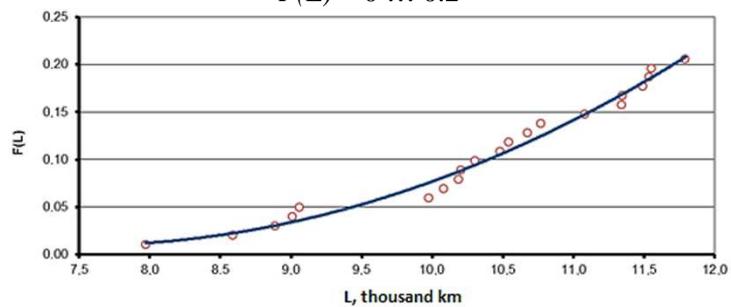


Figure 3. Approximation of empirical values of failure measure by a quadratic model in the interval of $F(L) = 0 \dots 0.2$

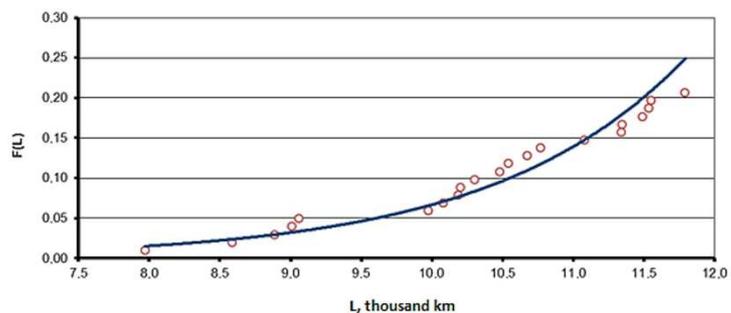


Figure 4. Approximation of empirical values of failure measure by an exponential model in the interval of $F(L) = 0 \dots 0.2$

For the listed models, Fisher's variance ratio, standard approximation deviation and approximation deviation at reliability measure 95 % $\varepsilon_{0.95}$ and 90 % $\varepsilon_{0.90}$ were calculated. Analysis of the obtained results shows the following.

All generated samples correspond to the chosen distribution law with probability not less than 0.99.

At approximation by a distribution law, Fisher's variance ratio is 2.8 to 26.2. For normal and lognormal distribution, laws variance is $20 - 2 - 1 = 17$; critical values are $F_{0.95}=2.11$ and $F_{0.99}=2.90$.

For Weibull's law, accordingly, $20 - 3 - 1 = 16$, $F_{0.95}=2.12$ and $F_{0.99}=2.92$. In 15 cases out of 16, distribution laws adequately approximate the empirical reliability measure with probability 0.99, and in one case probability is 0.95.

For the quadratic model, Fisher's variance ratio is 1.30 to 75.5, variation is $20 - 3 - 1 = 16$, critical values are $F_{0.95}=2.12$ and $F_{0.99}=2.92$. In 15 cases, the polynomial model adequately approximates the empirical reliability measure with probability 0.99, and in one case the adequacy hypothesis is not proven.

The exponential model adequately approximates the considered relation with probability not less than 0.99 in all cases, Fisher's variance ratio is 5.2 to 83, $F_{0.99}=2.90$ for a critical value for variety 16.

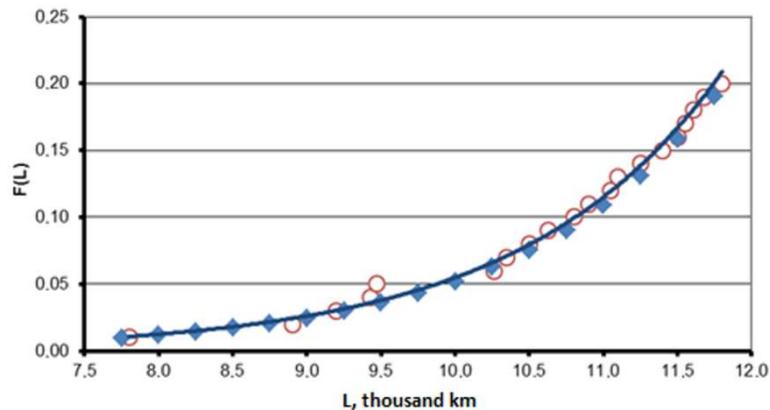


Figure 5. Approximation of empirical values of failure measure in the interval of 0 ... 0.20 by an exponential model: ○ – experimental values of failure measure; — – approximation of experimental values by an exponential model; ◆ – restored values of accumulated distribution

The least standard approximation deviation is provided by the exponential model, with the maximum value of 2.15 % and minimal value 0.6 %. For accumulated distribution, deviation is 1.10 ... 3.56, and for a polynomial model it is 0.20 ... 5.22, which is essentially higher. The least values of approximation deviation at the key points, which are reliability measure 0.90 and 0.95, are also provided by exponential model, $\varepsilon_{0.90}=0.06 \dots 2.58 \%$ and $\varepsilon_{0.95} = 0.02 \dots 1.39 \%$. For the distribution laws, deviation is $\varepsilon_{0.90}=0.50 \dots 2.99 \%$ and $\varepsilon_{0.95} = 0.29 \dots 3.64 \%$; for the polynomial model, it is $\varepsilon_{0.90}=0.14 \dots 7.25 \%$ and $\varepsilon_{0.95} = 0.20 \dots 5.22 \%$, which is also considerably higher.

Taking into consideration:

- a) a higher accuracy of the exponential model;
- b) the fact that the quadratic model has a bend in the field of low values of times to failure, which contradicts the physical meaning;
- c) the impossibility of estimating distribution parameters at a small share of realized times to failure with a sufficient accuracy, the exponential model should be preferred.

Thus, to determine the regularity of car engineering servicing in case when there is no representative sample of times to failure, the dependence of empirical failure measure on operating time can be approximated by the exponential model, and that model can be used to determine a regularity of engineering servicing that can provide the set reliability measure.

For the example in fig. 4, the model is:

$$F(L) = 3.1 \cdot 10^{-5} e^{0.74 L}.$$

The first derivative of that function is distribution density:

$$f(L) = 2.3 \cdot 10^{-5} e^{0.74 L}.$$

Dependence of failure measure on operating time is restored by integrating the previous relation (fig. 5, quadratic points). In the diagram, it is clear that the restored values are close to the experimental values, which allows using the offered method to solve practical tasks.

5. Conclusion

Approximation of the considered relation by accumulated distribution provides the worst result. Given that in the experiment, exact values of expectation and standard deviation were assigned, while in practice parameters of a distribution law are unknown, nonparametric models should be preferred.

The quadratic model adequately approximates empirical reliability measure with probability 0.99 in 15 cases out of 16. In one case, model's adequacy is lower than the critical level. Taking into account that, reliability measure changes according to operating time monotonously, but the quadratic model has a bend in the field of low probabilities; that model does not correspond to physical meaning.

The exponential model adequately approximates the considered relation with probability not less than 0.99 in all cases. Besides, the model provides a low standard approximation deviation (maximum

2.15 %), and low deviation in the zone of the standard engineering servicing regularity that is relevant to reliability measure 0.90 and 0.95. Thus, the exponential model meets the formulated requirements to the greatest extent.

Accordingly, to determine car engineering servicing regularity in case when there is no representative sample of times to failure, the dependence of empirical failure measure on operating time can be approximated by the exponential model, with the use of which engineering servicing regularity that provides a certain reliability measure can be determined.

6. Practical use of results

On the base of the conducted research, it is ascertained that to determine car engineering servicing regularity in case when there is no representative sample of times to failure, the dependence of empirical failure measure on operating time can be approximated by the exponential model, with the use of which engineering servicing regularity that provides a certain reliability measure can be determined.

To use the obtained results in practice in order to determine and correct engineering servicing regularity standard, it is necessary to collect failure data, determine set failure measure R_v and calculate the standard.

Using the $F(L)$ and L value pairs, exponential model parameters A_0 and A_1 are calculated:

$$F(L) = A_0 e^{A_1 L}.$$

For that purpose, combined equations are solved:

$$\begin{cases} \ln A_0 m + A_1 \sum L_i = \sum \ln F(L)_i \\ \ln A_0 \sum L_i \sum L_i + A_1 \sum L_i^2 = \sum L_i \ln F(L)_i \end{cases}$$

Model parameters are calculated using the following formulae:

$$A_0 = \exp \left(\frac{\sum \ln F(L)_i \sum L_i^2 - \sum L_i \ln F(L)_i \sum L_i}{m \sum L_i^2 - \sum L_i \sum L_i} \right);$$

$$A_1 = \frac{\sum L_i \ln F(L)_i - \ln A_0 \sum L_i}{\sum L_i^2}.$$

Engineering servicing regularity is determined with the use of these parameters and the value of the set reliability measure:

$$L_m = (\ln(1 - R_v) - \ln(A_0)) / A_1.$$

7. Inference

A scientific and practical task of increasing car reliability by operative determination and correction of engineering servicing regularity of cars operated in different conditions was solved on the base of conducted theoretical and experimental researches.

It is ascertained that for determination of car engineering servicing regularity in case when there is no representative sample of times to failure, the dependence of empirical failure measure on operating time can be approximated by the exponential model, with the use of which engineering servicing regularity that provides a certain reliability measure can be determined.

References

- [1] Bauer V I, Kozin E S, Bazanov A V, Nemkov M V and Mukhortov A A 2014 The methodic of forming a rational structure of a distributed production base of transport divisions in the pipeline industry. *Biosciences Biotechnology Research Asia* **11** 287-295
- [2] Zakharov N S, Savin S A, Ivankiv M M and Lushnikov A A 2014 Factors influencing on downtime of transport-technological cars under current repairs. *Oil Industry* **4** 82-84