Improving the reliability of the truck frame, taking into account maintenance frequency

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Abstract. In this work, the reliability of the KamAZ-4308 truck frame is increased, taking into account its maintenance frequency. This brand was chosen due to the fact that it is one of the best-selling cars in Russia among the cars with a gross weight of 14 to 40 tons in 2019. A method for optimizing the value of the intervals between the planned car maintenance (MAINT) is proposed. When calculating the reliability, the problem of minimizing the amount of initial data was solved in order to reduce the experiment time, its labor intensity and the financial testing costs. As one of the options for reducing unit costs, a change in the material for manufacturing a truck frame is considered. The empirical and approximating functions of the general totality of the finite volume (GTFV) of the Тр frame of the KamAZ-4308 service life are obtained. At a given failure rate $\lambda = 10^{-7} \text{h}^{-1}$, period values $\tau = 10 \text{h}$ and cost $U/C = 100$ the optimal frequency of maintenance is $T_{opt} = 993 \text{h} \approx 1,4 \text{month}$ taking into account the minimum technogenic risk $S_{min} = 0,0513$.

Introduction
Reliability issues are closely related to finding the ways to reduce labor, time and economic losses as a result of equipment failure. The development and application of methods for reducing the duration of tests, financial costs for conducting an experiment and obtaining the basic data is an urgent task in modern conditions. Minimization of costs for production, operation and prediction of the service life of a part can be achieved by reducing the volume of samples for strength, load and service life when calculating the vehicle reliability indicators.

Improving the reliability of truck components is inextricably linked to ensuring timely and high-quality maintenance. Optimization of the frequency and duration of MAINT time remain relevant.

1. Justification of the technical object choice
In this work, the reliability of the KamAZ-4308 truck frame is increased, taking into account its maintenance frequency. This brand was chosen due to the fact that it is one of the best-selling cars in Russia among the cars with a gross weight from 14 to 40 tons in 2019. Information on the position of the considered and other brands on the Russian market is presented in Figure 1.
OJSC “KamAZ” is the undisputed leader in the trucks supply to the Russian market. According to the company’s data, 35.5 thousand trucks were sold in 2019, more than 5 thousand vehicles of which were exported. Among the company’s buyers are such large enterprises as Gazprom, Rossiiskie Seti, Iteko-Russia, PC Rosneft, AM GROUP and others. In order to ensure the competitiveness of cars, the company needs to solve the problem of reducing the risks of equipment failure during operation, as well as increasing the service life of parts. Increasing the service life of the vehicle can be achieved by optimizing the time between the scheduled maintenance.

The KamAZ-4308 truck frame was chosen as the technical object of the study, since it is its basic part, a highly loaded supporting structure, which ensures the reliable operation of the machine as a whole in many respects by attaching the engine, chassis, transmission elements, body, cab and additional special equipment. This part is considered as a construction of increased responsibility, the operating features of which should be studied and improved to increase its reliability and efficiency of using the car as a whole.

It is known that the car frame is subjected to alternating bending and torsional loads, mechanical and human-caused influences, as well as the aggressive environmental influences (moisture, chemical agents to prevent road icing, vibration, and others). All these factors together lead to the appearance of defects in the part and, as a consequence, to a decrease in the durability of the part, a decrease in its service life.

2. Optimizing reliability

To ensure the optimal reliability of equipment and its components (Figure 2), it is recommended to strive to reduce the time of the experiment, its labor intensity, the number of tests and the financial costs of their implementation [1, 2]. This task can be solved by developing the methods for minimizing the amount of initial data for calculating the reliability indicators [3, 4].

In this paper, it is proposed to optimize the probability of failure-free operation of the truck frame \( P(t) \) by the criterion of unit costs \( C_i \) (Figure 3) taking into account the time length between maintenance. Reliability calculation is carried out using the method described in [5] and based on the use of small samples of strength, loading and service life. To model the general totality of a finite volume, the distribution of absolute ranges is used \( W_{rs} = x_r - x_s \) \( (r, s = 1, \ldots, n) \)

\[
F(W) = \int_0^W f(W)dW,
\]

where \( f(W) \) – is the shear density of the ranges (in general):
Minimization of the initial data amount for calculating the reliability indicators in order to reduce the experiment time, its labor intensity, financial costs for testing

Reducing the amount of initial data (sample size) in terms of strength, loading and service life, taking into account the failure reduction to a minimum value [6-8]

Calculation of the strength of samples and parts using indirect correlation dependences [9, 10]

Development of a methodology for reducing the amount of initial data (sample size) to obtain a set of finite volume

Choosing a method for calculating the fatigue limit by using indirect correlations with hardness and ultimate strength [11]

Improving the reliability of the truck frame by reducing unit costs when obtaining the initial data on the duration of the experiment, its labor intensity, manufacturing and operation of the part

Figure 2. Ensuring optimal reliability of equipment and its components
Figure 3. Optimization of the vehicle frame manufacturing option (and, accordingly, the likelihood of the vehicle frame failure-free performance)

In the course of modeling, empirical and approximating functions of the general totality of finite volume (GTFV) $T_p$ frame of the KamAZ-4308 car service life were obtained (Figure 4).

Figure 4. GTFV for the KAMAZ-4308 truck frame service life distribution functions:

1 – empirical; 2 – approximating

A change in the steel grade, wall thickness, an increase in the cross-sectional area of the frame and others were applied as the options for the frame manufacture.

An important aspect of this study is the accounting for maintenance, since maintaining the vehicle frame operability has a significant impact on the reliability of the entire vehicle as a whole. Timely maintenance in specialized automotive services makes it possible to reduce the risk of sudden failures, which leads to an increase in the vehicle operation safety and a decrease in the cost of extending its service life [12, 13]. It should be borne in mind that each element of the car may experience the implicit failures not determined visually or during conventional diagnostics, but can only be detected using the special monitoring and diagnostics tools. Having determined the functions of the probability dependences of no-failure operation and the failure rate on time $P(t)$ and $\lambda(t)$ accordingly, it is possible to solve the problem of optimizing the duration of the service life period of an object (car frame) between the scheduled maintenance. The financial costs of eliminating the hidden failures are denoted by $u$, then the unit costs for time are denoted by $\tau$. 
\[ S(\tau) = Up(t < \tau) + Cp(t \geq \tau) + u \int_0^\tau f(\tau - t)dt = U[1 - P(\tau)] + CP(\tau) + u \int_0^\tau [1 - P(t)]dt = \\
= U + (C - U)P(t) + u \left[ \tau - \int_0^\tau P(t)dt \right]. \]

The average unit costs over time \( \tau \)

\[ s(\tau) = \frac{1}{\tau} \left[ U + (C - U)P(t) + u \left[ \tau - \int_0^\tau P(t)dt \right] \right]. \]

Differentiating the expression in time and equating the derivative to zero, we obtain

\[ P(\tau) - \tau \frac{dP(t)}{dt} - \frac{u}{U - C} \left[ \tau - \int_0^\tau P(t)dt \right] = \frac{U}{U - C}, \]

Having solved this equation, we find the desired value of the optimal value of the maintenance frequency \( T_{opt} \).

Determining the size of the period between the scheduled MAINT, it is necessary to strive to minimize the quantitative risk value [14, 15], taking into account financial losses for the car restoration and repair, simple equipment and the entire mechanized complex of machines during work.

We represent the risk function as

\[ S = CP_2(t) + UP_3(t) \]

To obtain the practical results, let us consider the frame of a KamAZ-4308 truck. The choice of this technical object is justified at the beginning of this work.

3. Results of solving the optimization problem

To present the results obtained (Table), we denote the minimum amount of risk by \( S_{min} \), \( U/C \) – is the cost ratio of a sudden failure to the maintenance cost.

**Table 1.** The results of solving the problem of optimizing the intervals between the planned MAINT for the truck KamAZ-4308.

| \( \tau, \ h \) | \( U/C \) | Optimal maintenance intervals \( T_{opt} \) [h] |
|--------------|---------|-------------------------|
|              |         | \( \lambda = 10^{-8} \ h^{-1} \) | \( \lambda = 10^{-7} \ h^{-1} \) | \( \lambda = 10^{-6} \ h^{-1} \) |
| 10           | 10      | 9972                    | 3164                     | 982                      |
|              | 100     | 3252                    | 993                      | 317                      |
|              | 1000    | 995                     | 304                      | 93                       |
|              | 10000   | 326                     | 92                       | 24                       |
| 20           | 10      | 14136                   | 4457                     | 1396                     |
|              | 100     | 4463                    | 1394                     | 426                      |
|              | 1000    | 1384                    | 427                      | 121                      |
|              | 10000   | 429                     | 133                      | 27                       |
| 50           | 10      | 22331                   | 7032                     | 2195                     |
|              | 100     | 7032                    | 2187                     | 665                      |
|              | 1000    | 2188                    | 658                      | 173                      |
|              | 10000   | 658                     | 178                      | 36                       |
Analyzing the table, we find that, for example, for a given failure rate $\lambda = 10^{-7}$ h$^{-1}$, the period values $\tau = 10$ h and cost U/C = 100 the optimal maintenance frequency is $T_{opt} = 993$ h $\approx$ 1.4 month taking into account the minimum technogenic risk $S_{min} = 0.0513$.

4. Summary

In this article, the problem of improving the reliability of the frame of the KamAZ-4308 vehicle has been solved, taking into account the optimization of the intervals between scheduled maintenance. The values of the MAINT optimal frequency, depending on the failure rate, the costs of restoring the facility in case of a sudden failure, the size of the period and human-caused risk have been obtained.

References

[1] Deryushev V V, Zaitseva M M, Kosenko E E, Kosenko V V 2020 The quality analysis of the anti-corrosion coatings metal structures operating in difficult conditions *IOP Conference Series: Materials Science and Engineering* 913(4) 042059.

[2] Deryushev V V, Kosenko E E, Kosenko V V, Zaitseva M M 2019 Making technical decisions in conditions of uncertainty in the presence of risk *Safety of technogenic and natural systems* 2 56-61.

[3] Kotesova A A, Teplyakova S V, Popov S I, Kopylov F C 2019 Ensuring assigned fatigue gamma percentage of the components *IOP Conference Series: Materials Science and Engineering* 698(6) 066029.

[4] Deryushev V, Zaitseva M, Megera G, Fedyanov A 2019 A method for the identification of dynamic characteristics car suspension materials *IOP Conference Series: Materials Science and Engineering* 698 066031.

[5] Kasyanov V E, Rogovenko T N, Zaitseva M M 2013 Providing a given fatigue life of machine parts using small samples of initial data *Mechanical Engineering Bulletin* 5 10-15.

[6] Evseev D Z, Kotesova A A, Kosenko V V, Golubeva A Y 2019 Ways to Improve the Durability of Pneumatic Tires *IOP Conference Series: Materials Science and Engineering* 698(6) 066032.

[7] Deryushev V V, Zaitseva M M, Evseev D Z, Kosenko E E 2020 Concentration of thermal stresses in metal materials and constructions under local heating *Materials Science Forum* 974 729-734.

[8] Kasyanov V, Deryushev V, Shulkin L, Kosenko E, Kotesova A 2018 Endurance tests of single machines production *MATEC Web of Conferences* 224 02107.

[9] Veremeenko E G, Rogovenko T N 2020 Handling equipment reliability effect on grain terminal risks *IOP Conference Series: Materials Science and Engineering* 913(4) 042062.

[10] Teplyakova S V, Kotesova A A, Popov S I, Kotesov A A 2020 The transition from the sample data to the total aggregate of the final volume and the analysis of this transition laws *IOP Conference Series: Materials Science and Engineering* 913(4) 042054.

[11] Kasyanov V, Kosenko E, Kosenko V, Krymsky V 2020 Method for processing experimental strength data using statistical methods *ES Web of Conferences* 157 02019.

[12] Kasyanov V, Deryushev V, Kosenko E, Kosenko V, Golubeva A Y 2018 Synthesis of methods and principles of ensuring the reliability of one-off and serial production machines *MATEC Web of Conferences* 224 02106.

[13] Ivanov V V, Popov S I, Marchenko Ju V, Marchenko E V, Dontsov N S, Timofeev S A 2019. Thickness of vibrational mechanochemical solid-lubricant coating in friction pairs of transport engineering products "XII International Scientific Conference on Agricultural Machinery Industry (INTERAGROMASH 2019): IOP Conference Series: Earth and Environmental Science" 403 012115. doi:10.1088/1755-1315/403/1/012115.
[14] Kasyanov V E, Korotky A A, Egelskaya E V, Kosenko E E 2020 The algorithm for ensuring the parts’ (assembly nodes, machines) reliability based on the theory of risk *IOP Conference Series: Materials Science and Engineering* **913**(4) 042052.

[15] Panfilov A V, Deryushev V V, Korotky A A 2020 Recommended safety systems for a risk-based approach *Labor safety in industry* **5** 48-55.