Operating conditions calculation during three-dimensional process charts construction of the trucks reliability

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Abstract. The article shows that the existing methods of determining the trucks reliability do not take into account the level of load effect during the operation. Depending on climatic conditions, road surface categories, carrying capacity use conditions and technical service quality, the cumulative value of the load impact will vary and affect the reliability index. The purpose of the work is to identify the relationship between the reliability indices and the cumulative value of the impact, as well as a graphical interpretation of these dependencies using three-dimensional reliability process charts. In the paper the methods determining the accumulation rate of loading effects on vehicles and their impact on the probability of failure-free operation and the failure rate of trucks are used. The sequence of collecting statistical data on failures and operating conditions is given. The theoretical bases determining the operating reliability indices dependence on the loading action level are also discussed. The sequence of three-dimensional reliability process charts construction is presented. The obtained results give the possibility of updating the modes of maintenance for various makes and models of commercial vehicles taking into account the operating conditions.

1. Introduction
Due to the underdevelopment of the railway network in the Eastern regions of the Russian Federation, most of the goods are transported by trucks, the operation of which is associated with the need to solve complex technological problems concerning the multifactorial influence of load modes.

The main characteristic of the level of load influence \( W (L) \), exerted on the trucks in the course of handling, is the traction resistance coefficient \( \Psi_{\Sigma} \), evaluating the negative impact of all external factors, including the climate, exerted on the vehicle operational reliability in the course of transport works.

Since trucking is carried out by four categories of roads (I, II, III, IV), let us assume there are four levels of vehicle rigidity working conditions. When in operation on each of the categories of roads the average speed \( V_{ave} \) and the values of linear fuel consumption \( Q \) will change. Accordingly, with the predominance of a particular road category on route, the traction resistance coefficient \( \Psi_{\Sigma} \) will change. Its value is determined by the dependence (1) and directly depends on the values of \( Q \) and \( V_{ave} \).

\[
\Psi_{\Sigma} = k \cdot \frac{Q}{V_{ave}},
\]

where \( k \) – the coefficient of proportionality (in N/l·h), determined by the checking fuel consumption \( Q_{chc} \), the speed \( V_{chc} \) at the checking fuel consumption and the traction resistance coefficient with a flat hard surface \( \Psi' \), equal to 0.025 for wheeled vehicles [6].
The negative impact of climatic conditions on the technical condition of the trucks is characterized primarily by the environment temperature $t_{env}$. At low temperatures, when driving on a snow-covered road, the index $\Psi_2$ will certainly change. Firstly, this is due to a driver’s choice of the speed mode, when performing hauling operations on such a road surface. Secondly, this happens because of an increase in fuel consumption under low temperature conditions. Thirdly, there is an increase in engine and transmission wear-life owing to oil viscosity intensifying in these vehicle components.

2. Materials and Methods

Thus, during the operation in cold climatic conditions, a truck is influenced by environment impacts, estimated by the following parameters: the traction resistance coefficient $\Psi_2$, the average speed in the specified operating conditions $V_{ave}$, the load factor $\gamma_e$, the environment temperature $t_{env}$. The indices $Q$ and $V_{ave}$ can be remotely monitored, which allows not only to determine the numerical values $\Psi_2$ and, consequently, $W(L)$, but also to predict the impact of environmental conditions on the vehicle operational reliability depending on the values of $P(L)$ and $\lambda(L)$.

The parameters of external influences affect the performance parameters, which can be used to assess the service reliability in difficult conditions during the vehicle operation. The operation parameters include: $N$ – engine power; $M$ – the torque transferred to the transmission; $g_c$ – specific fuel consumption; $L_{res}$ – the vehicle residual life; $P(L)$ – reliability probability; $\lambda(L)$ – failure rate; $\omega(L)$ – the assessed failure rate.

It is proposed to evaluate the negative impact of the parameters of external influences on the truck operation parameters, which can be used to assess the operational reliability by means of discrete and continuous monitoring of the vehicle diagnostic variables.

The study revealed that, in a cold climate, the vehicle efficiency and operation safety depend on the condition and stability of the engine and transmission components. The vehicle test parameters, allowing to identify their impact on the functioning parameters, are: $\delta$ - the pressure in the main oil line; $\theta$ – the wear of the sleeve-piston joint; $e$ – the change in the law of the valve motion; $\kappa$ – the radial clearance in rolling bearings; $\varphi$ – the backlash of rollers, pins and axes; $\tau$ – the backlash of wheel gear teeth by thickness.

The parameters of control actions, of course, affect the diagnostic parameters, so their set in combination with the action of external parameters depends on the vehicle operational reliability in a cold climate [5]. The parameters of the control actions include: $\alpha$ – acceleration time; $J$ – time rate of change (deceleration); $t_{br}$ – driver reaction time; $N_M$ - the number of maintenances conducted; $t_M$ – the complexity of the maintenance operations performed.

3. Results and discussion

As noted above, the complexity of the operating conditions is determined by the load rate $W(L)$, the value of which, to a greater extent, is a function of the traction resistance coefficient $\Psi$.

However, the current method of determining $W(L)$ does not take into account the influence of the mass of the transported cargo $m_c$ on the change in the technical state of the frame, suspension elements, engine, transmission and brake systems. The generated levels of stiffness presented in [3] are designed for road construction and carrying and lifting machines. Mainly, the loading effect on hydraulic systems, attachments and crawler-mounted equipment is taken into consideration, therefore, to determine $W(T)$, in the technique the author used the auxiliary coefficients $J_{tech}$ – the stiffness indices.

The specifics of the truck operation is completely different and, to a greater extent, the loading of units, assemblies and frames occurs due to the action of the cargo mass being transported and its fluctuations in the process of moving along the road irregularities. It is advisable to introduce a carrying capacity utilization factor, allowing to estimate the load on the vehicle units during operation. Modern cargo control sensors give the possibility to monitor the value of this coefficient, and together with the
monitoring of the values of the indicators of $Q$ and $V_{ave}$, it is appropriate to track the magnitudes of the cumulative value of the charging exposure level \[ \sum_{i=1}^{n} W(l_i) \] [1, 2].

In this regard, it is proposed to transform the basic formula of the existing methodology and introduce the carrying capacity utilization factor into it:

\[
W(L) = \psi \sum L_{\text{dict}} \cdot \gamma_c \cdot (N^k \text{km}),
\]

where $L_{\text{dict}}$ — vehicle net running under operating conditions.

It is put forward to evaluate the influence of the level of load impact on the vehicle technical condition, taking account of the running $l_i$, using the cumulative value of the level of load impact \[ \sum_{i=1}^{n} W(l_i) : \]

\[
\sum_{i=1}^{n} W(l_i) = W(l_1) + W(l_2) + W(l_3) + \ldots + W(l_n), (N \cdot \text{km}),
\]

where \[ \sum_{i=1}^{n} W(l_i) \] is the amount of load impacts during the vehicle runnings $l_i$.

The detection of reliability characteristics of the discrete diagnosis and at the stage of collecting statistical data about failures with the indicator \[ \sum_{i=1}^{n} W(l_i) \], there is a possibility of the analytical problem solution of the vehicle operation efficiency and safety increasing.

The main drawback of the existing methodology is the lack of any information about the truck operating conditions and the specifics of transport operations. The dependence of the reliability probability $P(L)$ on the vehicle run $L$ [4,5] is estimated using the traditional approach of constructing reliability process charts. The reliability probability is the probability that an element or system will perform specified functions and store parameters within the specified limits during a given period of time and under certain operating conditions. Forming $P(L)$ values, the initial number of observed $N$ and the number of vehicle failures $N_0$ per running increment $\Delta L$ are considered. In other words, at the stage of statistical data collection, the values databases of a specific number of failures per running are formed, ignoring the information on the circumstances under which these failures have occurred. The absence and lack of accounting statistics on the category of road surface, temperature loads, weight of cargo transported at the time of the vehicle failure, as well as the quality of maintenance checkups do not allow the specialists of service stations to assess the causes and nature of specific failures with greater reliability [2].

In this regard, it is proposed to pay more attention not only to the number of failed elements, but also, above all, to the circumstances under which they have arisen, at the stage of collecting retrospective data on actual vehicle faults. It is necessary to collect statistics with two indicators — the number of failures for a certain running $n_i(l)$ and the magnitude of the load impact $W(l_i)$.

The fixed numerical values of the level of load impact $W(l_i)$ at the time of failure, including the running $l_i$, allow us to estimate the cumulative value of the level of load impact \[ \sum_{i=1}^{n} W(l_i) \], individually for each unit of the truck park. Thus, the indicator of the vehicle reliability probability $P[L,W(L)]$ is estimated more accurately and based on the specifics of the transport operations performance, allowing to identify elements limiting operational reliability in various situations for each individual commercial vehicle.

In this case, the vehicle reliability probability $P[L,W(L)]$ will be determined as follows:

\[
P[L,W(L)] = \frac{N[L,W(L)] - N_0[(L + \Delta L),[W(L) + W(\Delta L)]]}{N[L,W(L)]}.
\]

3
Accordingly, the number of vehicle failures $N_o$ per running $L$ and the cumulative value of the load effect $W(L) + W(\Delta L)$ is estimated by the formula:

$$N_o(L + \Delta L)(W(L) + W(\Delta L)) = N[L,W(L)] - P[L,W(L)] \cdot N[L,W(L)],$$

(5)

where $\Delta L$ – running increment, $L$ – total running, $N[L,W(L)]$ – a number of observed vehicles in specified operational conditions, $W(\Delta L)$ – load effect increment per running $\Delta L$.

The reliability process charts are suggested to be designed according to three parameters: the reliability probability $P[L,W(L)]$; $L$ – the vehicle running and the level of load impact $W(l_i)$ at the time of failure, taking into account the running $l_i$. The example of a three-dimensional reliability process chart is shown in Figure 1.

![Figure 1. Three-dimensional process chart of truck reliability.](image)

Increasing the value $\sum_{i=1}^{n} W(l_i)$ results in decreasing the value $P[L,W(L)]$. This means that the reliability probability does not depend, to a greater extent, on the vehicle running, but it is dependent on the conditions under which it has been operated. With the running growth, the elements, whose failures are associated with wear, will limit the reliability. Their service life relies on the nature of the change in the failure rate. The geometric shape of the plane in the three-dimensional diagram will depend on the nature of the failures. The plane presented on the three-dimensional reliability process chart characterizes the failures, which are distributed according to the normal distribution law. These are the failures associated with wear of brake pads, cylinder group parts, gear teeth, wheel tires, etc.

Additionally, the failures can be distributed according to the exponential law, i.e., for example, the failures associated with the destruction of the leaf spring, and the law of the Weibull-Gnedenko, i.e. the failures related to the fatigue of the parts and their subsequent degradation [5, 7].

By analogy, as well as for the indicator of the reliability probability, the dependence for the indicator of failure rate $\lambda[L,W(L)]$ is constructed. The failure rate $(L)$ is a number of failures per unit time, referred to the number of elements remaining faultless at the beginning of the period under consideration. In this case, the failed elements are not replaced. The example of such dependence is shown in Figure 2:
\[ \lambda[L, W(L)] = \frac{N[L, W(L)] - N[(L + \Delta L), W(L + \Delta L)]}{\Delta L \cdot N[L, W(L)]}. \quad (6) \]

With this interpretation of the vehicle failure rate \( \lambda[L, W(L)] \), it is possible to objectively assess the frequency of occurring failures.

**Figure 2.** The dependence of the failure rate on the cumulative value of the load impact level.

### 3. Conclusion
Taking into account the statistics of failures and commercial vehicle operating conditions, not only reliability indicators \( P(L) \) and \( \lambda(L) \) are estimated, but also the dependencies between them and the cumulative value of the load impact \( \sum_{i=1}^{n} W(l_i) \) are revealed with the help of three-dimensional reliability process charts. This allows to adjust the modes of the vehicle maintenance and repair, optimize the cost of maintenance and repair operations, that enhances drivers’ safety when performing transport operations in difficult conditions.

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