Justification of integrated reliability index of vehicles

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Abstract. In modern automobile transport, the methodology of probabilistic estimates of the time between failures of automobiles, which has been developed over decades, is not used, and manufacturers do not include data on their reliability in the characteristics of automobiles. With their distribution of cars on flights and routes, the motor transport enterprises do not calculate the margin of their performance before repair or maintenance. The aim of this work is to substantiate automation methods for a comprehensive reliability assessment of a car and determine the residual life before setting up for repair or maintenance. It is proposed to use for these purposes statistical estimates of the operating time parameter between statements for repair or maintenance and their change as the vehicle develops a resource. A new service for the on-board local area network of vehicle has been developed to automatically monitor the performance margin. It is based on a joint automatic control of statements for repair or maintenance and calculation of vehicle operating time between them. The proposed control is intended to be implemented by means of the on-board local area network of the car and the information system for supporting the technical operation of cars at the motor transport enterprise.

1. Introduction
When allocating vehicles to consignors and distributing them along flights and routes, the operators at the motor transport enterprise are mainly guided by information about the drivers, rather than the reliability of the vehicle. The transportation service, as well as the engineering and technical service of motor transport enterprise, have information about vehicles only about their admission to work, their "age", previous repairs and their costs. Motor transport enterprises do not have data on the performance margin and faultlessness of vehicles.

When determining the useful life of vehicles, the dynamics of their faultlessness are not calculated, being limited only to accounting data for component replacements and associated costs, as well as the technical availability coefficient. There is no record of operating time for vehicle failures, and its automation in motor transport is extremely inconvenient and more than problematic. Reliability assessment methods do not go beyond the scientific environment [1, 2]. A paradoxical situation has arisen in which motor transport does not use the methodology of probabilistic estimates of the time between failures of technical objects, developed by decades, and manufacturers do not include data on their reliability in the characteristics of vehicles. During the vehicle operation, instead of failures, replaceable components are recorded.

Vehicle purchasers are also deprived of information about their reliability, including faultlessness, availability and durability. Manufacturers are not legally required to provide such information. But the problem also lies in the fact that the comprehensive reliability indicators common to technical objects,
introduced, including GOST 27.002-2015 (GOST 27.002-2015 Reliability in technics. Terms and definitions), are not used by motor transport. For vehicles, there are no generalizing comprehensive indicators of reliability technologically acceptable for automation of their accounting.

Reliability theory in its present form does not provide a practical, comprehensive indicator of reliability acceptable for vehicles. As comprehensive indicators of reliability, the fundamental interstate standard GOST 27.002-2015 provides for the coefficients of availability, operational availability and technical use. Neither the first nor the second indicators are suitable in practice for a generalized assessment of the vehicle reliability and are not used in motor transport. For their determination with regard to vehicles, there are no calculation methods and no account is taken of the required initial data.

The coefficient of technical use (in motor transport referred to as the coefficient of technical availability) and specific downtime in maintenance and repair are not quite suitable for this, because to a greater extent depend not on the reliability of vehicle, but on the organization of work in the engineering and technical service of motor transport enterprise, or the performance of work by a car service.

The developments proposed methods for assessing the reliability of vehicles not by time between failures, but by the values of their residual life [3, 4]. A methodological study was also proposed for assessing the impact on the reliability of mechanical systems of indicators of their reliability of their components under conditions of uncertainty in the structure of the system [5, 6].

At the same time, representatives of transport science are seeking comprehensive reliability indicators that summarize at the same time several particular properties of the reliability of vehicles. For example, to model the evolution of the reliability of an object using data from monitoring its condition and parameters of changing operating conditions, methods for predicting the technical resource have been proposed [7, 8].

A solution to a similar problem for predicting the faultlessness resource of a dynamic object was proposed for the conditions of limited available information about the probabilities of failures [9]. The advantages of this method are undeniable in operating conditions, where probabilistic estimates of faultlessness and accounting of the data required for their calculation on failures of vehicles are difficult.

The possibilities of predicting the reliability of technical objects at the early stages of their design, when it is still possible to take the least costly measures to increase their faultlessness, were analyzed using the non-parametric Bayesian network methodology in [10].

Mean time between failures, reflecting only a particular property of faultlessness, also cannot serve as a comprehensive indicator of reliability. With regard to vehicles, the unsuitability of indicators of time between failures to automate their accounting is even more significant. Such records are not kept either at the transport enterprise or at the car service, and its introduction is more than problematic.

The registration of time between failures of vehicles is complicated by the vague concept of “failure” as applied to vehicles, for which exact strict criteria of “failure” have not been introduced. So, the interstate standard GOST 27.310-95 (GOST 27.310-95 Reliability in technics. Analysis of the types, consequences and critically of failures. Key points) establishes the rules for assigning failure criteria, but not these criteria for different types of equipment. It is no coincidence that the time between failures is not calculated either in Russian or in foreign motor transport.

Availability, as a particular property of reliability, depending on the reliability, maintainability and recoverability of an object, GOST 27.002-2015 determines its ability to be in a state in which it can perform the required functions in specified modes and conditions of use, maintenance and repair. But introducing the property of readiness, this standard does not give its indicators.

Meanwhile, the international standard IEC 60050-692 (2017) (IEC 60050-692(2017) International electrotechnical vocabulary - Part 692: Generation, transmission and distribution of electrical energy - Dependability and quality of service of electric power systems) contains an indicator of a comprehensive assessment of the reliability of vehicles that is quite suitable for automating its control by the already used technical means: the average duration of a working state (mean up time),
characterized by the mathematical expectation of the time of a continuous working state of an object. In fact, this is nothing more than an indicator of the availability of the object, generally reflecting the totality of its levels of faultlessness and maintainability properties. However, taking into account that the operating time of the vehicle is measured not only by time, but also by mileage, instead of "duration" it is more rational to use a more general indicator with regard to vehicles: "performance margin of the vehicle".

2. Material and methods

Owners of vehicles and officials operating vehicles are more interested in information about the duration of continuous maintenance of vehicles. When choosing a vehicle model for purchase and when determining the useful life of vehicle at a motor transport enterprise or when a personal vehicle is replaced, the duration (or mileage) of continuous maintenance (i.e., margin) of the vehicle operability is of paramount importance. It is interrupted by statements for repair and maintenance of vehicle to eliminate failures, malfunctions and the next maintenance. The reliability of vehicles in a generalized form most clearly reflects the statistics of changes in the duration of maintaining the working capacity of vehicles in operating units (thousand km or hours) as the life of the vehicle is reached from the start of operation to decommissioning. This is a comprehensive indicator that summarizes the particular properties of the reliability and maintainability of vehicles, which allows to expand the established understanding of the availability property. An indicator of the operating margin of vehicle will be a statistical assessment of the duration of continuous operability or the mileage between successive statements for repair or maintenance operations. However, to assess the performance margin, the parameter of the average mileage \( L_i \) between successive statements for repair or maintenance of vehicle is more suitable.

It can be formed by the information system of motor transport enterprises or the vehicle dashboard by summing the shift distances \( l_k \) between the next (i-1) and i-th vehicle statements for repair or maintenance:

\[
L_i = \sum_{k=1}^{P} l_k
\]

where \( L_i \) is the value of the i-th unit run of the vehicle between statements for repair or maintenance;

\( P \) is the number of complete or incomplete shifts worked on the vehicle between the (i-1)-th and i-th statements of the vehicle or maintenance.

Due to the random nature of the vehicle failures, the value of \( N \) is also random and the spread of \( L_i \) operating time between the vehicle statements for repair or maintenance is comparable to the minimum frequency of maintenance, but due to the failures of the vehicle it does not reach the minimum maintenance interval.

As the vehicle resource is depleted, it is significantly reduced by 4...6 times or more by the time the vehicle is removed from the register (Figure 1).
Figure 1. Illustration of a decrease in the probability density $f(L)$ of the mileage between successive statements for repair or maintenance as the vehicle resource is depleted.

Where: $F(L_1), F(L_2), F(L_3)$ – change in the probability density of the operating time between statements for repair and maintenance from the start of operation to the cancellation of vehicle, respectively; $L_{1av}, L_{2av}, L_{3av}$ – median mileage distributions between statements for repair and maintenance; $L_M$ - maintenance interval.

Two significant advantages distinguish the proposed assessment of the reliability of vehicles according to the statistics of operating time between statements of vehicles for repairs or maintenance from the known methods for assessing statistics of failures: reflecting not only the faultlessness properties, but also maintainability, and this is no less significant, the ability to automate the accumulation of initial data and performance margin calculation.

The advantage of the proposed assessment of the reliability of vehicles in terms of operating margin over the known methods of statistical estimation of residual life by economic indicators of operating the vehicle is that it is not so much tied to operating conditions as to the reliability of vehicles. Therefore, the new indicator more narrowly and unambiguously characterizes precisely the property of availability of vehicles, including personal use vehicles. Manufacturers will have a new opportunity to evaluate this reliability property even before the release of vehicle into circulation.

It is proposed to calculate two statistical estimates of the vehicle performance margin based on the deterministic values of $L_i$ operating time recorded between the statements for repair and maintenance during operation: a successively updated current estimate after each repair and maintenance, and step-by-step estimates for different stages of the vehicle resource development, for example, every 100...250 thousands km of mileage.

The initial data for calculating the mileage between the repair and maintenance statements is the daily or shift mileage in relation to the time and marks on the statement for maintenance and repair. Therefore, accounting for the proposed indicator for the vehicle fleet is easily automated by software on the motor transport enterprises or directly on the vehicle by a local network and means of displaying an intelligent dashboard.

To obtain updated current statistical estimates of operating time between successive statements of vehicles for repair or maintenance, it is proposed to use the last 10 or 12 before calculating the successively fixed operating time $L_i$ ($i=1, 2, ..., 10$). As more and more new $L_i$ values accumulate, a
sequential update of the statistical estimates of this parameter is possible. For example, the simplest statistical assessment of the vehicle performance margin will be the mathematical expectation of $L_0$:

$$L_0 = \frac{1}{M} \sum_{i=1}^{M} L_i$$

(2)

Automatically recorded values of operating time (mileage or time) between vehicle statements for repair or maintenance can also automatically calculate point-based statistical estimates of the density distribution of the performance margin parameter of the vehicle. The estimates obtained will be suitable for comparison with those received for vehicles of the same “age” and destination employed in similar traffic.

In addition to or instead of point-based statistical estimates, interval estimates of the residual life of the vehicle, for example, gamma-percent resource, can be automatically generated. Such estimates will show the operating time, after which the vehicle with probability $\gamma$, expressed as a percentage, will have to be put in for repair or maintenance (Figure 2).

![Figure 2](image.png)

Figure 2. The function $f(L)$ of the probability density of the distribution of the vehicle operability resource $L$, interpreted by the gamma distribution with the offset parameter $L_0 = L_M$ and the gamma percentage resource $L_\gamma$.

It is proposed to calculate stepwise assessments of the performance margin for predefined levels of $L_R$ vehicle resource development (for example, $L=0.2L_M$; $L=0.5L_M$; $L=0.8L_M$) by the last 10...15 before reaching the corresponding level successively fixed operating time $L_i$ between statements for repairs and maintenance received for the same degree of development of a resource or the same operating time from the start of operation.

The dynamics of the obtained statistical estimates of the performance margin will be more eloquent than the declarations of the manufacturer and the subjective assessments of the operators to characterize the reliability of each vehicle model for each type of transportation.

In this case, the total resource $L_0$ for the vehicle will be a non-independent summing function, derived from the set $N$ of mileage indicators $L_i$ between successive statements for repair and maintenance:

$$L_0 = \sum_{i=1}^{N} L_i$$

(3)

where $N$ is the number of vehicle statements for repair and maintenance during the service life.

The current updated assessment of operating time between statements for repair or maintenance is applicable in the operational work of transportation services of motor transport enterprises to distribute vehicles by flights and routes, depending on the probable residual life of the vehicle before repair or maintenance and the length of the flight. For such an application, it is necessary to calculate for each vehicle the average value of the operating time parameter $L_i$ between statements for repair or
maintenance, the value of $L_{0i}$ between operating time after the last $i$-th statement for repair or maintenance and the probable residual life $R_{(i+1)}$ to the expected next $(i+1)$-th statement for repair or maintenance (Figure 3):

$$R_{i+1} = L_i - L_{0i},$$

moreover $L_{0i} = L_F - L_{0i}$, and $L_{0i} = \sum_{i=1}^{M} L_i$.

Where $L_F$ is the actual operating time (mileage on the speedometer or hours on the counter) at the time of calculating the residual life $R_{(i+1)}$;

$L_{0i}$ is the total mileage cumulatively from the beginning of the vehicle operation;

$M$ is the number of vehicle statements for repair or maintenance.

![Diagram of vehicle operating time calculation](image)

**Figure 3.** Illustration of the countdown of operating time of the vehicle between the next statements for repair or maintenance.

At the same time, for each flight or route, vehicle must be selected whose probable residual life $R_{(i+1)}$ exceeds the length of the route (flight) with the required minimum margin.

For individuals operating vehicles, such current estimates of the probable residual life before statement for repair or maintenance will give objective information about the timeliness of diagnosing and preparing the vehicles.

Stepwise estimates of operating time between vehicle statements for repair or maintenance for the given stages of the degree of resource development are applicable as markers of reliability of vehicles of different models.

Both manufacturers of vehicles and motor transport enterprises can form them. Such markers will facilitate the choice of vehicles by purchasers. During operation, they can be used as technical indicators of the timeliness of replacing aging worn-out vehicles as part of fleets operated by legal entities.

Manufacturers will have the opportunity to automate the collection of source data not only on the reliability of the vehicles as a whole, but also on their components. They can use this data to increase the equal strength of automotive components in the preparation of operational documentation and in the development of algorithms for diagnosing vehicles.

3. Results

The proposed estimates of the vehicle performance margin are convenient for automating their receipt, including registration of the initial data and calculations of the given indicators. A service that provides control of the residual life of the vehicle before the upcoming statement for repair or maintenance can be implemented both by the information system of motor transport enterprises and by the local network of the vehicle. The algorithm for automatic control of the residual life of the vehicle before the statement for repair or maintenance includes two main components: registration of statements for repair or maintenance and resource calculations by software (Figure 4).
|   |   |
|---|---|
| 1 | Registration of i statements of vehicles for repair or maintenance |
| 2 | Registration of date, time and total operating time \( L_0 \) of the vehicle at the moment of statement for repair or maintenance |
| 3 | Calculation of operating time \( L_i \) of the vehicle from the prior to next statement for repair or maintenance |
| 4 | Ranking of the last 10…12 sequentially registered statements of vehicles for repair or maintenance |
| 5 | Approximation of obtained set of operating times by the theoretical law of distribution |
| 6 | Calculation of upcoming gamma percentage resource \( L_\gamma \) of vehicle from the last to upcoming statement for repair or maintenance |
| 7 | Registration of fact operating time \( L_F \) after last statement for repair or maintenance |
| 8 | Calculation of projected with probability \( \gamma \) residual life of the vehicle before the upcoming statement for repair or maintenance |
| 9 | Registration of gamma percentage resource \( L_\gamma \) of vehicle calculated upon reaching the ruble values of the total operating time \( L_0 \) of vehicle (\( L_0=100, 200, 300, \ldots, 1000 \) thousands km of mileage) |

**Figure 4.** The structure of the algorithm for automatic assessment of the predicted residual life of the vehicle before statement for repair or maintenance.

In both forms of service implementation, there are various options for registering the moments when a vehicle is set up for repair or maintenance.

At a motor transport enterprises with a developed engineering and technical service, the time and date of statement for repairs either manually or by maintenance is recorded in the documents. Therefore, it will be sufficient only to “tie” the operating time of the vehicle (mileage or operating hours) to these time and date stamps. Similarly, mileages between repairs and maintenance of vehicles under warranty will be recorded at the service station.

It is also possible to manually register the moments of statement for repair or maintenance of modern vehicles, the local network of which includes the function of a flexible maintenance system.

Automatic registration of the moments when the vehicle is set up for repair or maintenance is feasible by various technological means.

For vehicles operated on motor transport enterprises with a modern engineering and technical service, it is possible to register hits in the maintenance and repair workshops according to the GSM coordinates of these workshops.

It is possible to automatically record the entry of vehicles equipped with a radio frequency scanner into the maintenance and repair workshops, or auto repair workshops equipped with passive RF tags at the entrances. This technology is used, for example, to recognize electronic keys. This is the least costly “democratic” technology.

The same technology is applicable when equipping vehicles with sensors for signal recognition (for example, short-range radio communications such as Wi-Fi) from sources located at the entrances to the maintenance and repair workshops.
Recognition of statement the vehicle for repair or maintenance by the inputs to the on-board local area network of the vehicle through the OBD connector for scanning malfunctions or by transferring it to the external control mode on unmanned vehicles is also applicable.

A service for automatic control of the residual life before statement for repair of vehicles serviced by several service enterprises or in isolation from service bases is implemented by software on-board local area network of vehicles with minimal additional equipment for service enterprises (Figure 5).

![Figure 5. The structure of the equipment complex for monitoring the residual life of vehicles, by several service enterprises or operated in isolation from service bases.](image)

To control the residual life of vehicles serviced by one service enterprise, we use a set of equipment that includes software of the operating service enterprise and on-board control and automatic data transmission modules (Figure 6).

![Figure 6. The structure of the equipment complex for monitoring the residual life of vehicles serviced by one service enterprise.](image)
4. Conclusions

For the technical operation of automobiles, a new service is proposed that automates the periodic updated formation of generalized estimates of the performance margin and as the resource is developed. The use of such estimates will eliminate errors in the distribution of vehicles by flights and routes for commercial transportation, including the transport of dangerous, especially valuable, oversized and heavy cargoes, and will facilitate the choice of a vehicle model by purchasers.

References

[1] Duc-Hanh Dinh, Phuc Do, Benoit Iung 2020 *Computers & Industrial Engineering* **144** 106443 https://www.sciencedirect.com/science/article/abs/pii/S0360835220301777
[2] Lolas S, Olatunbosun O A 2008 *Expert Systems with Applications* **34**(4) 2360
[3] Chinedu I Ossai 2019 *Reliability Engineering & System Safety* **182** 142
[4] Ji Hwan Cha, Maxim Finkelstein 2019 *Reliability Engineering & System Safety* **188** 118
[5] Petek Yontay, Rong Pan 2016 *Reliability Engineering & System Safety* **152** 104
[6] Gero Walter, Simme Douwe Flappe 2017 *Reliability Engineering & System Safety* **168** 227
[7] Tao Tao, Enrico Zio, Wei Zhao 2018 *Reliability Engineering & System Safety* **177** 35
[8] S Vorobyov, I Chernyaev, V Nazarkin, K Filippov 2017 *Transportation Research Procedia* **20** 695
[9] Wang Zhonglai, Liu Jing, Yu Shui 2020 *Reliability Engineering & System Safety* **195** 106756
[10] Dongjin Lee, Rong Pan 2018 *Reliability Engineering & System Safety* **171** 57