The Study and Management of Reliability Parameters for Automotive Equipment Using Simulation Modeling

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Abstract. The author considers the issue of formation research activity competence of future cadets in the system of military education. This issue is up-to-date because of the necessity to increase the quality of military specialists' training. The solution, in the author's opinion, is in realization of the model of scientific and research competence of military school cadets.

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1. Introduction

In the conditions when automobilization is growing and the competitive struggle on the car market is escalating, the reliability of automotive equipment becomes one of the main factors of its competitiveness. The problem of car reliability assuring is solved in all phases of life cycle – from design to recycling. While using a car one should bear in mind that any technical equipment, even the perfect one, cannot function for a long time without proper operating conditions and a high-quality and timely maintenance [1, 2].

The character of impacts can be studied on the basis of the information about failures occurring in operation. These failures are fixed in the form of customer's reclamations that are carefully processed and analyzed. Both the classification of failures by various factors and the method of malfunction data formalization in the form of failure codifier allow us to monitor and analyze this information [3].

2. Methods.

The analysis of failure data shows that each car model has a number of parts that break down more often than others in certain operating conditions and with a fixed running time. These parts are called "reliability limiting" or "reliability-critical". At the same time G.V. Kramarenko notes [1] that, among 15-18 thousand of parts a car consists of, 3-4 thousand have shorter life time than a car itself, but only 400 parts are reliability-critical.

The most efficient method of increasing car reliability is failure preventing based on the prediction of technical state with a certain running time and on planning, thereby, a service life. The prediction of a possible failure means the assessment of probability whether a controlled parameter will go beyond the limits after a certain period of time. This makes it possible to plan spare parts delivery, by items and quantity, for timely replacement of unreliable elements according to operating conditions; climate in this region; a season; type, model and configuration of a vehicle.

3. Main part.

The most reasonable way of accumulating failure statistics is to use the opportunities of information systems and technologies, such as data base management systems. They allow us to describe all kinds of failures by type, location and conditions a car was used in. Besides, there are statistical analysis programs that promote the decrease of premature failure risks. It is necessary to have a system of collection, formalization and analysis of reclamation reports. With the help of this system, technicians will be able to input reclamations and a producer company will be able to look through and analyze reclamations.

When someone turns to a service facility, the information system fixes data concerning the reasons. Then this information is analyzed. At the same time, only one factor is used for sorting, other factors stay fixed. The parameters of random distribution laws of a trouble-free life are determined with the help of the "Statistica" program for a formed data array [3, 4]. Besides, they construct a graph of distribution law according to the histogram of empirical data, and detect its compliance with sampled data at the set significant level.

The analysis data are used to work out and correct manuals for service facilities and car owners. Meeting the requirements listed in these manuals ensures the reliability of a car (Figure 1).

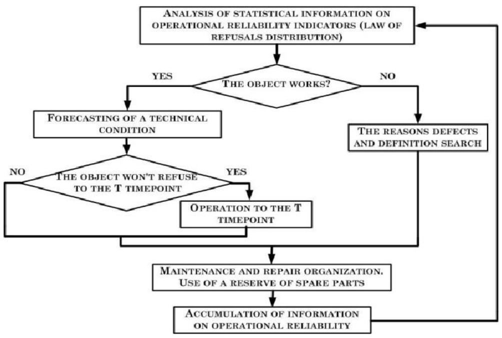

Figure 1. The algorithm for accumulating and analysis of information about automotive equipment failures during operation.

For increasing the efficiency of spare parts delivery planning, it is necessary to take into account that various units, assemblies and systems of a car have different life time and reliability depending on many stochastic factors.

Car failure occurs at moment T_{otk} that can be predicted with a certain probability. As the analysis of operating characteristics shows, failure intensity λ(t) is divided into three operating stages. In the running-in period there are many failures caused by manufacturing defects, as a rule. In the period of normal operation, failures are occasional and sudden, usually caused by mishandling, load change, unfavourable external factors etc. In the third period, the failure intensity increases, caused by aging and continuous usage. Taking in consideration the above, spare parts delivery should include functionally different mechanisms.

Usually the prediction of normal operating failures is aimed to operational planning for a short period of time (down to several days). The long-term planning of possible customers' visits because of car failures is made for a period from one week to several months.

It is impossible to fight with failures in the period on running-in, but one can easily forecast the time intervals when the wear becomes critical and leads to failure. This is the basis for prevention – the prediction of failures.

In order to increase the operating reliability in the running-in period, with a glance to its specificity, it is necessary to make a long-term prediction for a *T* value which is equal to this period duration.

The analysis of data received by the chain of service centers belonging to a producer company showed that the total mileage influences the number of failures, labour costs and maintenance costs. At the same time, the technical readiness coefficient, annual mileage and productivity go down.

In predicting failures of automotive vehicles, the failure intensity index is used at all stages. This index is connected with reliability function *P(t)* by the formula

$$\lambda(t) = -P'(t) / P(t) \qquad (1)$$

In this case, failure intensity is widely used in processing observations on objects in operation. If the failure probability is quite little, the intensity is close to probability density when $t = T$ [5, 6].

The statistical estimate $\breve{\lambda}(t)$ for failure intensity can be accepted in the form

$$\breve{\lambda}(t) = \frac{n\left(t + \frac{\Delta t}{2}\right) - n\left(t - \frac{\Delta t}{2}\right)}{\left[N - n(t)\Delta t\right]} \qquad (2)$$

A duration Δt is chosen in a way that it contains enough values t_k and it is short enough in comparison with total time on test or observing. It is necessary to have large samples to satisfy these contradictory requirements.

The statistical processing of results makes it possible to choose the appropriate analytical dependencies for index change in time and to assess the numerical values of necessary parameters. For irrecoverable elements of trouble-free operation probability *P(T)*, or for failure intensity [lambda].

If the failure intensity is set, formula (1) can be considered as a differential equation concerning function *P(T)*. Solving this equation with starting condition *P(0)=1* gives:

$$P(t) = \exp\left[-\int_0^t \lambda(\tau)d\tau\right] \qquad (3)$$

If the failure probability in the initial time *t=0* is nonzero, then instead of (3) we will have:

$$P(t) = P(0)\exp\left[-\int_0^t \lambda(\tau)d\tau\right] \qquad (4)$$

If a moment of running-in end is assumed as a start of operation, and if a moment of normal operation end is assumed as a limit state, then we can regard [lambda]=*const* in operation duration. As a result, instead of (4) we get:

$$P(t) = \exp[-\lambda t] \qquad (5)$$

Formula (5) expresses the reliability law that is widely used for failure predicting at the stage of normal operation. The mathematical expectation of life time is equal *1 /* [lambda]. That is why we can write down formula (5) in the form:

$$P(t) = \exp(-t / t_c), \qquad (6)$$

where $t_c = E[T]$

The probability of failures in the running-in period is calculated using a model based on Weibull distribution. The trouble-free operation probability is calculated as

$$P(t) = \exp\left[(-\frac{t}{t_c})^{\beta} \right], \qquad (7)$$

where t_c and β are positive parameters.

Now we'll consider the following operating process: a car assembly is operated until the moment of failure. Then it is replaced by a new one taken from the same standby consignment, and then it is used until failure and replaced, and so on. Suppose the replacement duration is shorter than an interval between consecutive failures. We will describe this process by means of sequence *t1, t2,…* of failure moments. An interval between failures is a random variable. That is why this sequence is a stream of random events. The compliment-on-one of the function of time allocation between neighbouring events concurs with the trouble-free probability *P(t)*. If according to the statement this probability does not depend on the number of an event in the stream, then the stream is stationary, recurrent and markovian. If reliability function *P(t)* has a form (3), the stream of random events is Poisson. The probability of failures *k* on duration [0,t] meets the Poisson law.

$$Q_k(t) = \frac{(\lambda t)^k}{k!} \exp(1 - \lambda t) \quad k = (0,1,...) \qquad (8)$$

When $k=0$ we get $Q_0(t) \equiv P(t)$.

The models of random failure streams are widely used in reliability theory. In this case, along with failure streams they introduce renewal streams, the steams of service operations etc. In the system theory of reliability, it is accepted that the number of possible states of elements and systems is finite. That is why the models of random failure streams with finite set of values can be a handy tool for describing objects in the conditions of maintenance and renewal [7].

Thus, if we have remaining life data $t_{pec,}$ calculated on the basis of failure probability *P(t)*, it is possible to find the probable date of failure for any unit, assembly or system:

$$T_{otk} = T_n + t_{res}, \qquad (9)$$

where T_n is the start date of prediction forestalling.

The date of probable failure is one of the main factors that are taken into account in spare parts delivery planning. At the same time, in the conditions of foreign market when service centers are far from the producer of spare parts, it is necessary to send a shipment order to the producer to the intent that a spare part is received within the time limit:

$$T_{st} \geq T_{otk} - t_{per,} \qquad (10)$$

where T_{st} is a date of order sending;

t_{per} is a total execution time of delivery.

If conditions $t_{res} = t_{per}$ are fulfilled, it is necessary to replenish the supplies of this kind of spare parts. Considering the stochastic character of delivery execution time t_{per} and remaining life t_{res}, it is necessary to correct the above mentioned condition: $t_{res} \geq t_{per}$. It means that a spare part delivery order should be sent to the producer on or prior to the date $T_{st} = T_{otk} - t_{per}$. Practice shows that an order should be sent several days before this date.

A consignment is based on the minimization of cumulative costs for uncalled spare parts storage and rush delivery of required nonstick spare parts. If $Z_{fine} > Z_{storage}$ then a spare part is included in delivery package, otherwise it will be delivered at the moment of failure [8].

The mathematical model of spare parts delivery optimization consists in finding the constrained minimum:

$$Z = 1/2 \cdot B \cdot (\tau - t_n) \cdot \sum_{i=1}^{N} \sum_{j=1}^{M} \lambda_{ij} \cdot h_{ij} \cdot k_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{M} g_{ij} \cdot q_{ij} + \sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \cdot (S_{ij} + q_{ij}) \cdot p_{ij} \to \min \qquad (11)$$

with limitations:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} h_{ij} - d_{ij} \sum_{i=S+1}^{\infty} p_i \geq 0, \qquad (12)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{M} d_{ij} \sum_{i=S}^{\infty} p_i - h_{ij} \geq 0, \qquad (13)$$

where: q_{ij} $(i = \overline{1,N}),(j = \overline{1,M})$ is a volume of spare parts consignment; *M* is a number of foreign regions, *N* is a total number of nomenclature in the consignment; λ_{ij} is a failure intensity of *i* parts, units and assemblies in *j* operating region; k_{ij} is the existing stock in service centers; S_{ij} is a minimum stock level value; g_{ij} are the costs; h_{ij} are the storage costs; d_{ij} is the cost overrun for an urgent delivery in comparison with an ordinary one.

$$d_{ij} = \sum_{i=1}^{N} \sum_{j=1}^{M} \left(\frac{\lambda_{ij} B^2}{2 g_{ij}} - \frac{1}{h_{ij}} \right) \qquad (14)$$

A simulation model was worked out for experimental investigation. The application package AnyLogic was chosen for its implementation. Spare parts delivery management is a model with many approaches. It unites the discrete-event simulation and agent model. A car with a certain configuration and modification used in a certain region acts as an agent there [9, 10]. The model is implemented with the help of a status map (state chart). A synchronization algorithm was used for transmitting model streams from a discrete-event model to an agent model.

4. Conclusion.

The analysis of data received from a chain of service centers belonging to a truck producer company showed that the total mileage influences the number of failures, labour costs and maintenance costs, while the technical readiness coefficient, annual mileage and productivity go down.

At the same time, the analysis of data about failures of cars used in different conditions makes it possible to improve prediction of possible visit of each customer. It increases the efficiency of service facility work by the optimization of service stations workload and supplying service zones with necessary spare parts. Besides, the timely replacement of parts is an effective tool for preventing a sudden outage of a car and improvement of its operating reliability. Solving these problems requires the analysis of huge statistic data arrays from different regions where a car is used. This can be done using the technology of working with multidimensional data arrays and simulation modeling.

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