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Identification of the Actual Distribution of Demand for Spare Parts in Car Maintenance Service Stations

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Abstract: The main goal of the work is to choose the theoretical distribution function most consistent with the empirical function of fault distribution based on the analysis of statistical information of previous replenishment periods about the failures of details of each type of par value. This information should be accumulated on daily information about the replacement of spare parts of failed parts in vehicles that arrived during the entire period of replenishment for maintenance at this service station. The choice of the best theoretical distribution function in this sense is made from a set of a finite number of competing parametric distributions (exponential, normal, log-normal, We bull, monotonic and no monotonic diffusion) by Kolmogorov-Smirnov's test. The advantage of this criterion in comparison with other consent criteria is that, along with an estimate of the accuracy of the approximation of the empirical failure distribution function. The mutual reversibility of the processes of distribution of the operating time to failure (to failure) and the number of failures is established, the relationship between the expressions for the distribution function of the operating time to a fixed number of failures and the function of the distribution of the number of failures for a fixed operating time to failure is obtained. This ratio allows you to choose the best distribution model based on the available fault statistics of parts (and replacing them with the corresponding spare parts) in the previous planning periods.

Keywords: Poisson Flow, Distribution Function, A Set of SPIA, Operating Time Until Failure, Diffusive Distribution, Critical Value of Statistics, Importance Level of the Hypothesis

1. Introduction

The SPİA kit must include the spare parts needed to repair and maintain the product's performance for a certain period of time (SPİA replenishment period) and ensure the required level of reliability of the latter. Recently, in service stations, the problem of determining the need and providing spare parts necessary for the continuity of the maintenance (TS) and car repair process is acute. In this regard, studies relevant to identifying factors affecting the need for (CTSS) in spare parts and developing methods for determining their needs are relevant [1, 2, 3, 4, 5]. Conditionally, all methods for determining the demand for demand in automotive spare parts can be divided into three groups [2]:

- according to the nomenclature norms, which establish the average annual consumption of a particular component per 100 vehicles per year. The bases for the determination of nomenclatural norms are data on the reliability of parts and the method of their conversion into demand [6]. As a rule, the nomenclature rate is calculated for certain reference conditions. This method is used by automakers to determine the volume of production of spare parts for the entire fleet of vehicles in operation. CTSS (service stations) can also use this method to calculate the need for spare parts, and in the absence of such norms, according to actual requirements;

- on the actual market demand for spare parts (the flow of claims), which are properly collected and analyzed. Such methods allow obtaining the most accurate results on the actual need for automotive spare parts; - mixed method, providing a combination of the first two.

As a result of the analysis of previous works carried out in [2], it has been established that recently the majority of Russian auto dealers use in their work the system for determining the need for spare parts, which is based on the actual market demand for individual parts for the previous period of work. Further calculation of the size of the optimal batch of ordered parts is carried out on the basis of the Wilson mathematical model of deliveries used abroad [1].

Thus, the accuracy of determining the need for spare parts of CTSS according to the methods developed earlier and currently used is not sufficient. Therefore, there is a need to develop a better methodology for determining the need for spare parts in service stations.

Classification of the basic models of inventory management makes it possible to use them in conditions of unstable consumption. Examples of models of inventory management in the presence of fluctuations in demand are given in [7]: it is a model with a set periodicity of replenishment of the reserve to a constant level and a model of "Minimum-maximum". These models are based on the use of elementary mathematical actions in the calculation of the basic parameters. The classical formula for calculating the optimal order is the Wilson formula and its various modifications [1, 7]. Meanwhile, probability theory makes it possible to significantly expand the apparatus for calculating the parameters of classical models.

For the incoming stream of applications, we denote by $Z_k(t,\tau)$ the event consisting in the appearance of exactly k applications on the half-open interval $[t,t+\tau]$ under the application we will understand the next arrival in the car service center of a car with faulty parts, generally speaking, of different types. The properties of the flow of applications can be characterized by the probabilities $\{p_k(t,\tau)\}$ of such events. A flow is called stationary if these probabilities are determined only by the length of the interval τ and do not depend on its position on the time axis t. A stream is called a stream without aftereffect if the events $Z_{k_1}(t_1,\tau_1)$ and $Z_{k_2}(t_2,\tau_2)$ are independent for non-overlapping time intervals. The flow is assumed to be ordinary if the probability of occurrence of more than one event on the elementary section [t, t + Δt] is of the order of smallness of 0 (Δt), i.e. Above Δt.

A stream that simultaneously satisfies all three of the listed requirements is called the simplest one [1].

From probability theory it is known that for the simplest flow the probability of coming to [0, t] is exactly to the requirements (requests)

$$p_k(t) = \frac{(\lambda t)^k}{k!}, k = 0,1,\dots,,$$

where λ = 1/a, a is the average interval between requirements.

This formula defines the Poisson distribution with the parameter λt, which is why the simplest flow is also called Poisson flow.

When forming the need of car service enterprises in spare parts, it is usually assumed [1, 2] that the random flow of claims for spare parts consumed at car service stations (CTSS) is described by the Poisson distribution. Taking into account that for large values of the number of spare parts k, the Poisson distribution with a good approximation can be described by the normal distribution law, in practice the normal distribution law is used both to determine the need for spare parts of the spare parts department ($Q_{\_mag}$) [4, 5], and for the need for spare parts of the auto service (Q_{serv}) [7].

However, in general, the flow of applications is not the simplest and, therefore, Poisson. In this case, all three requirements can be violated. In addition, the number of applications k in the given time period may not be large enough and the use of the normal distribution of the flow of applications becomes unreasonable.

When developing the algorithm for calculating spare elements in single SPIA-S kits, the following assumptions are accepted [8]: the equipment under study consists of non-renewable elements connected in series (which are replaced by spare ones in case of failure, and those that are refused are sent to the repair base); The reliability of the workers and spare parts of each standard is the same; During storage, spare parts are not refused; All operating elements are refused independently.

Depending on the purpose of the equipment, its maintenance and repair, the reliability requirements of the equipment in agreement with the supplier of spare parts, the replenishment period (T_{PZ}) can be taken equal to a quarter, half a year, to one or several years, although the proposed algorithm for calculating the planned SPIA volume is acceptable and for longer periods.

The most important a priori information, which ultimately determines the amount of spare parts, is the theoretical model of failures, adopted in the calculation of the number of failures [9, 10, 11].

In the present paper it is proved that the time between failure T and the occurrence of the number of failures R are mutually invertible processes. As the competing hypotheses, we have tested six known parametric distribution functions of the running time T (including diffusion no monotonic (DN) and diffusion monotonous (DM) distributions.) For fixed t, each of these distributions corresponds to the distribution function $F_R(r)$ of the failure rate R and back to each fixed The failure rate r corresponds to the distribution function $F_T(t)$ of the running time T.

Among the six corresponding distribution functions $F_R(r)$ for the best, we take the best one for the best one, which, by Kolmogorov-Smirnov's agreement criterion, is closest to the empirical distribution function of the random variable R for a given significance level α.

Competitive theoretical distribution functions

(1). Exponential distribution

The exponential distribution function of the operating time *T* has the following form:

$$E(t;\lambda) = 1 - exp(-\lambda t), \tag{1}$$

where $\lambda = \frac{1}{\mu_T}$, λ is the intensity of the change T; μ_T - is the mathematical expectation (ME) of the random variable (as abbreviated form r. v.) of the operating time *T*, the sample estimate $\hat{\mu}_T$ is the average value $\hat{\mu}_T = \frac{1}{n}\sum_{k=1}^{n} t_k$, $t_k = k$, k in our case is the number of the working days, $n = 27$ –is the number of working days in the period of $T_{RP} = 1$ month. In the designation $\mu_T = 1/\lambda$ expression (1) takes the form:

$$F(t;\ \mu_T) = 1 - exp\left(-\frac{t}{\mu_T}\right) \tag{2}$$

(2). Normal distribution (N)

The normal distribution function:

$$N(t; \mu_T, \sigma_T) = \Phi\left(-\frac{t-\mu_T}{\sigma_T}\right) \tag{3}$$

where $\Phi(z) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{z} exp\left(-\frac{x^2}{2}\right)dx$ standardized normal distribution with $\mu = 1$ and dispersion $D = 1$; $\sigma_T = \sqrt{D_T}$, D_T is the dispersion of r. v., T, with a sample estimate; ; $\widehat{D}_T = \frac{1}{n}\sum_{n=1}^{n}(t_k - \mu_T)^2$

In this expression n is replaced by n-1 for great n.

For suitable use, the distribution function is parameterized. In the parameters as μ_T and $\nu_T = \sqrt{D_T}/\mu_T$, where ν_T is the coefficient of variation for r. v. T, the normal distribution function is written in the following form;

$$F_T(t; \mu_T, \nu_T) = \Phi\left(\frac{t-\mu_T}{\mu_T\nu_T}\right) \tag{4}$$

(3). Logarithmic normal distribution (LN)

The logarithmic normal distribution function

$$LN(t; \mu, \sigma) = \Phi\left(\frac{ln\, t-\mu}{\sigma}\right) \tag{5}$$

where

$$\mu = \ln\mu_T - \frac{1}{2}\ln\left(1 + \frac{D_T}{\mu_T^2}\right) = \ln\mu_T - \frac{1}{2}\ln(1 + \nu_T^2)$$

$$\sigma = \ln\left(1 + \frac{D_T}{\mu_T^2}\right)^{1/2} = \ln\left[\left(1 + \nu_T^2\right)\right]^{1/2}$$

In parameters μ_T, ν_T, expression (3) takes the following form

$$F_T(t; \mu_T, \nu_T) = \Phi\left(\frac{\ln\left[\frac{t\left(1+\nu_T^2\right)^{1/2}}{\mu_T}\right]}{\left[\ln\left(1+\nu_T^2\right)\right]^{1/2}}\right) \tag{6}$$

(4). Waybill distribution (W)

Distribution function

$$W(t;\ a, b) = 1 - exp\left[-\left(\frac{t}{a}\right)^b\right] \tag{7}$$

Where $b \approx \frac{1}{\nu_T}$ (witherror $\delta \leq 0,15$);

$\Gamma(z)$ is gamma function.

In parameters μ_T and ν_T expression (4) takes the following form;

$$F_T(t; \mu_T, \nu_T) = 1 - exp\left\{-\left[\frac{t\Gamma(1+\nu_T)}{\mu_T}\right]^{1/\nu_T}\right\} \tag{8}$$

(5). Diffusive non-monotonic distribution (DN)

$$F_T(t; \mu_T, \nu_T) = DN(t; \mu_T, \nu_T) = \Phi\left(\frac{t-\mu_T}{\nu_T\sqrt{t\cdot\mu_T}}\right) + +exp\left(\frac{2}{\nu_T^2}\right)\cdot\Phi\left(-\frac{t+\mu_T}{\nu_T\sqrt{t\cdot\mu_T}}\right) \tag{9}$$

(6). Diffusive monotonic distribution (DM)

Distribution function

$$F_T\ (t; \mu_T, \nu_T) = DM(t; \mu_T, \nu_T) = \Phi\left(\frac{t-\mu_T}{\nu_T\sqrt{t\mu_T}}\right) \tag{11}$$

To establish the connection between the distributions of the operating time until the failure T, and the number of failure, R, random varieties T_{r_0} and R_{r_0} (abbreviated as r. v.) are introduced for the arbitrary detail, and the random varieties T_{i,r_0} and R_{i,r_0} are introduced for the i -th type. In this case, r. v. with values t, $t \leq t_{r_0}$ where $t_{r_0} = r_0 \cdot T_0$, T_0 - is the mathematical expectation of the operating time until failure for any part; R_{r_0} is a r. v. of failures number with the values r, $r \leq r_0$, $r_0 = t_{r_0}/T_0$. The validity of the equalities is provided as follows:

$$\mu_{T_{r_0}} = T_0 \cdot \mu_{R_{r_0}} \tag{12}$$

$$\nu_{T_{r_0}} = \nu_{R_{r_0}} \tag{13}$$

for any part and equality, the followings are taken:

$$\mu_{T_{r_{i,0}}} = T_{0,i} \cdot \mu_{R_{r_{i,0}}}, \tag{14}$$

$$\nu_{T_{r_{i,0}}} = \nu_{R_{r_{i,0}}}, \tag{10}$$

this expression is for the parts of the i -the nominal type standard, where $T_{r_{i,0}}$ is r. v. with the values $t, t \leq t_{r_{i,0}}$, $t_{r_{i,0}} = r_{i,0} \cdot T_{0,i}$, $T_{0,i}$ -- is the mathematical expectation of the operating time until failure for any part of i -th nominal type r. v. failures with values $R_{r_{i,0}}$, r_i, $r_i \leq r_{i,0}$, $r_{i,0} = t_{r_{i,0}}/T_{0,i}$.

The distribution functions of the varieties T_{r_0} and R_{r_0} are related by the following correlation:

$$F_{T_{r_0}}\left(t; \mu_{T_{r_0}}, \nu_{T_{r_0}}\right) = F_{R_{r_0}}\left(r; \mu_{R_{r_0}}, \nu_{R_{r_0}}\right)$$

which allows us to pass from the distribution functions 1^0-6^0 of the variety T to the distribution functions of the variety R.

Such a relationship of the random variates T_{r_0} and R_{r_0} is of great importance because, as a rule, an auto-service enterprise has a database on the number of failures (i.e. replaced) of each type on the base of cars incoming on the service on working days (see, for example, table 1).

2. Selection of the Most Appropriate Model for the Distribution of the Part Failures

For the selection of the most appropriate model among the above six theoretical models of distribution we use the Kolmogorov-Smirnov agreement criterion, the essence of which is as follows.

Assume, $x_1, \dots, x_{n_0}$ is a given sample of n_0 independent observations and $x_{(1)}, x_{(2)}, \dots, x_{(n)}$ $(n \leq n_0)$ are sequenced in ascending order of different sampling values. The cumulative (accumulated) distribution function (the sample function of distribution) is defined as follows:

$$S_n(x) = \begin{cases} 0, x < x_{(1)}; \\ \frac{r}{n}, x_{(r)} \leq x < x_{(r+1)}\ (1 \leq r \leq n-1); \\ 1, x_{(n)} \leq x \end{cases} \quad (15)$$

Kolmogorov statistic has the following form:

$$D_n = sup_x |S_n(x) - F_0(x)|, \quad (16)$$

where $F_0(x)$ is the hypothetical distribution function.

Critical values d_α of statistics D_n for the levels $\alpha = 0,05; 0,01; 0,01$ with $n \leq 50$ are given in table 12.12.1[10]. For $n > 50$, the critical value d_α can be approximately calculated as [10].

$$d_\alpha = \frac{1}{2n}\left\{\ln\left(\frac{2}{\alpha}\right)\right\}^{1/2} \quad (17)$$

Statistic D_n is free from distribution, in this case, it is taken as follows:

$$P\{D_n \leq d_\alpha\} = \alpha \quad (18)$$

Where from we find the confidence interval for $F_0(x)$

$$P\{S_n(x) - d_\alpha \leq S_n(x) + d_\alpha \text{ при всех } x\} = 1 - \alpha$$

i.e. with a confidence probability $P = 1 - \alpha$, distribution function $F_0(x)$ is located in the following interval:

$$S_n(x) - d_\alpha \leq F_0(x) \leq S_n(x) + d_\alpha \quad (19)$$

No other agreement criterion gives such a conversion of criterion in the confidence interval.

In the calculations, the Kolmogorov-Smirnov's criterion will be used and the agreement $S_n(x)$ with $F_0(x)$ will be verified with three test values $= \alpha_i\ (i = 1,2,3)$: $\alpha_1 = 0,05$; $\alpha_2 = 0,01$; $\alpha_3 = 0,01$. Since the critical value d_α of the statistic D_n of the values of $\alpha = \alpha_i$ и $\alpha = \alpha_{i+1}\ (i = 1,2)$ differ by the quantity not less than $\varepsilon = 0,03$,, the following decisive rule is accepted:

if $D_n < d_{\alpha_1} - \varepsilon$, then the hypothesis H_0 is accepted with a sign importance level $\alpha = \alpha_1$;

if $d_{\alpha_1} < D_n < d_{\alpha_2} - \varepsilon$, then hypothesis H_0 is accepted with a importance level $\alpha = \alpha_2$;

if $d_{\alpha_2} < D_n < d_{\alpha_3} - \varepsilon$,, then hypothesis H_0 is accepted with a importance level $\alpha = \alpha_3$;

if $D_n > d_{\alpha_3}$, then hypothesis H_0 is deviates; in this case it can be agreed that the hypothesis H_0 is accepted with a importance level $\alpha_0 = 1$, i.e. with a confidence probability $P = 1 - \alpha_0 = 0$.

The initial data on the failures of the replaced parts an auto-service enterprise in the order of incoming cars in each of the 27 working days are given in table 1.

***Table 1.** Initial data on the failures of the replaced parts.*

Days	Engine	Suspension	Body	Total	the number of incoming cars
1	35	2	2	39	13
2	18	3	2	23	8
3	33	10	4	47	16
4	33	5	5	43	18
5	28	5	3	36	13
6	28	3	6	37	17
7	37	7	3	47	21
8	66	3	9	78	28
9	26	8	3	37	15
10	38	6	4	48	17
11	17	9	2	28	8
12	32	3	8	43	19
13	37	27	3	67	38
14	40	8	80	128	36
15	48	15	10	73	34
16	41	9	77	127	35
17	25	4	3	32	11
18	25	13	8	46	26
19	14	3	1	18	12
20	48	4	4	56	25
21	37	7	7	51	22
22	50	10	7	67	38
23	20	2	10	32	13
24	14	3	13	30	11
25	58	15	71	144	61
26	37	7	17	61	25
27	34	13	14	61	31

On the base of original date from Table 1 for failure parts r_k $(k = 1, \dots, n_0;\ n_0 = 27)$ in i -th working day we calculate cumulated sun of the failure parts to k: $r_k^H = \sum_{k'=1}^{k} r_{k'}$ time moment, t: $r^H(t) = \sum_{k \leq t} r_k$ and stepwise function of the continuous time is introduced on the time scale t with a measurement unit of one working day.

A sample of values is taken from table 1 $\{r_k^H\}$ $(k = 1, \dots, n_0;\ n_0 = 27)$.

Assume $r_{(1)}^H, \dots, r_{(n)}^H$ $(n \leq n_0)$ is a variation series corresponding to the sample.

$$S'_n(r^H) = \begin{cases} 0, r^H < r_{(1)}^H; \\ \frac{k}{n}, r_{(k)}^H \leq r^H < r_{(k+1)}^H\ (1 \leq k \leq n-1); \\ 1, r_{(k)}^H \leq r^H. \end{cases} \quad (20)$$

The theoretical distribution functions determined by the markers (1^0) – (6^0): exponential $(j = 1)$, normal $(j = 2)$, logarithmic normal $(j = 3)$, Weibull $(j = 4)$, diffusivenon-monotonic $(j = 5)$, and diffusive monotonic distribution $(j = 6)$ may be denoted by $F_j(r^H)$.

For each j $(j = 1, \dots, 6)$, we compute one's own $\alpha^{(j)} \in$

$\{d_j\}_{j=0,1...,3}$, by which the null hypothesis $H_0: F(r^H) = F_j(r^H)$ is accepted with a importance level $\alpha^{(j)}$ (i.e., with a confidence probability $P_j = 1 - \alpha^{(j)}$). If hypothesis H_0 is accepted for several distributions with the same level of importance $\alpha \neq \alpha_0$, then for the most appropriate distribution model, one of them is chosen for which D_n most of all deviates from d_α.

To describe the distribution function of the failures of particular type of parts in the expression for r_k^H it is sufficient to replace $r_{k'}$ to $r_{i,k'}$, where $r_{i,k'}$ is the number of failures (i.e. replaced) part of i -type in k working day.

The corresponding computer programs are developed to determine the best failure distribution of any part $F^*(r^C)$ and the parts of each i -th nominal type of the standard $F_i^*(r_i^C)$.

The results of the calculations are given in table 2 and 3.

Table 2. *The critical values d_α of the statistics D_n.*

	min	*max*	α
1	0	0,294	0,05
2	0,294	0,352	0,01
3	0,352	0,421	0,001
4	0,421	1	0

Table 3. *Determination of the best failure distribution of any part and parts of each model.*

Method	Engine		Suspension		Body		Total	
	D	α	*D*	α	*D*	α	*D*	α
1	0,172	0,95	0,196	0,95	0,32	0,95	0,198	0,95
2	0,89	0	0,899	0	0,99	0	0,923	0
3	4,27	0	14,3	0	8,3	0	4,5	0
4	0,675	0	0,5	0	0,32	0,99	0,53	0
5	0,16	0,95	0,182	0,95	0,29	0,95	0,172	0,95
6	8,9	0	79,1	0	47,1	0	11	0

It is seen from tables 2 and 3 that, for any part, the best distribution function is $F(r^C) = F_5(r^C))$ and for the parts of the nominal type the best distribution function is $F^*(r_i^C) = F_5(r^C)$, with $i = 1{,}2$ and $F^*(r_i^C) = F_4(r_i^C)$ with $i = 3$.

The calculation of the number of the elements in a set of SPIA based on more appropriate failure models leads to more effective planning of SPIA.

3. Conclusion

Identification of an adequate model of the distribution of failures of car parts that have to be replaced by spare parts in a car service company plays an extremely important role in improving the accuracy of calculating the demand for spare parts.

In reliability theory, the calculation of the failure distribution function usually uses their main characteristic - the time between failures, and in the absence of such information, information on the number of failures at certain points in time is used. Auto service enterprises have, as a rule, information about failures. In this connection, the work shows that the time between failures T and the occurrence of the number of failures R are mutually invertible processes and, as the main result, the relationship between the distribution function of the operating time to a fixed number of failures and the function of the distribution of the number of failures for a fixed operating time to failure. This makes it possible to select the best model for the distribution of the demand for spare parts by Kolmogorov-Smirnov's consent criterion based on the available failure statistics (with the corresponding replacement of the parts that failed in service for vehicles) in previous planning periods.

Since the fatigue wear of one part by diffusion affects the performance of other parts of the car, when choosing the best model for the distribution of failures, along with the traditionally used parametric distribution models (exponential, normal, lognormal, We bull), the list of competing models of the distribution of magnitude (monotonous and monotonic) Diffuse distributions (DM and DN), which naturally increases the quality of choice.

Unlike other criteria of agreement, the Kolmogorov-Smirnov criterion together with the estimation of the quality of choice gives the confidence probability of approximating the empirical distribution function by a blow-out theoretical distribution function, i.e. In addition, it evaluates the reliability of the calculated need for spare parts.

The proposed method for determining the best model for the distribution of failures of vehicle parts can be used in railway, air and water transport, as well as in other technical branches.

The established relationship between the distribution of the operating time before failure T and the number of failures k makes it possible, when planning the need for spare parts in the service center, to perform all necessary calculations based on failure statistics in previous periods of replenishment of the spare parts inventory SPIA.

Identification of an appropriate model of the failure distribution (and therefore replaced in a car service) of car parts is have great increasing in improving the accuracy of calculating the spare parts. The established relationship between the distribution of the operating time until failure T and the number of failures k makes it possible to carry out all the necessary calculations based on statistic failures in previous replenishment periods of SPIA, while planning the demand for spare parts in the auto-service enterprise.

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