DOI: 10.12731/2227-930X-2016-4-23-36

EVALUATION OF THE FREQUENCY OF DIAGNOSTICS OF COMPONENTS AND ASSEMBLIES FOR TRANSPORT AND TECHNOLOGICAL MACHINES ON THE BASIS OF HIDDEN MARKOV CHAINS

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In this article a statistical analysis of supply volumes of spare parts, components and accessories was carried out, with some persistent patterns and laws of distribution of failures of major components revealed. There are suggested evaluation models of components and assemblies reliability for the formation of order management procedures of spare parts, components and accessories for the maintenance and repair of transport and technological machines. For the purpose of identification of components operational condition there is proposed a model of hidden Markov chain which allows to classify the condition by indirect evidence, based on the collected statistics.

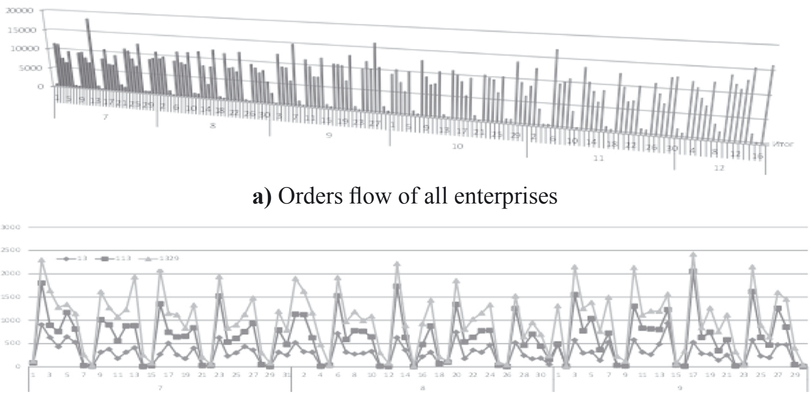
Keywords: *Transport machines; diagnostics; components and assemblies; Markov chains; statistical analysis; maintenance; repair and orders management.*

1. Introduction

In the general case, maintenance services of transport and technological machines can be divided into the following main groups [1–3]: preventive, aimed at routine maintenance (diagnostics, mounting, checking, oiling and adjusting works after a certain run); repair – carried out for elimination of failures appeared and restoring to working condition (replacement or repair of components, devices and assemblies, as well as body, fitting and mechanical, electro-mechanical works and other); ensuring operation – supply of fuel, oil, antifreeze and others. Thus the problem of modeling the reliability schemes and preventive replacements for the formation of components and assemblies reserves of auto transport enterprise (ATE) is relevant enough [4–6].

2. Statistical analysis of failures of components and assemblies for transport and technological machines

Solution of the problem of supply control synthesis is primarily based on the prognosis of various financial indicators [7]. The carried out analysis of the dynamics of order flow in a number of enterprises included in the service area of one dealer network, allowed to plot a chart of the volume of orders given in Fig. **1**.a. Rankings of ATE by the order flow volume showed that almost 20% of the orders flow accounts for 5 of the 200 enterprises. For the first three ATE conducted more detailed analysis of the orders flow (Fig. **1**.b). It demonstrates a significant correlation within certain groups of spare parts (Fig.**2**.a) [8, 9]. There was conducted an analysis of autocorrelation functions of time series (Fig. **2**.b).



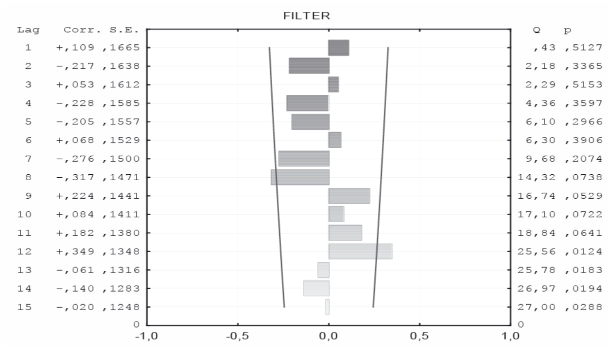
a) Orders flow of all enterprises

b) Orders flow of the main enterprises

Fig. 1. Time series of orders flow for accessories

Variable	Means	Std.Dev.	AIR_REF	GASKET	FILTER
	Correlations (Rez_Sol_2_Корр.sta) Marked correlations are significant at p < ,05000 N=33 (Casewise deletion of missing data)				
AIR_REF	14213,97	5843,132	1,000000	0,956394	0,987831
GASKET	20482,39	8065,382	0,956394	1,000000	0,965744
FILTER	20334,42	8275,620	0,987831	0,965744	1,000000

a) Table of correlations



b) Autocorrelation function

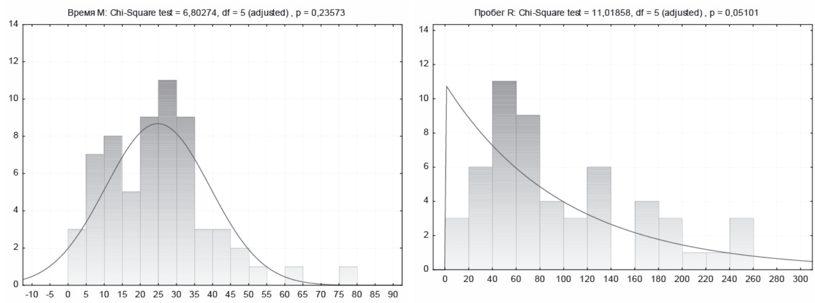
Fig. 2. The average monthly demand rate for the main parts

On the basis of the carried out analysis of the demand rate for spare parts and accessories it is given a task of modeling of time series with the set (obtained on the basis of statistics) values of correlation evaluations and autocorrelation functions.

In terms of repair of the platform lifting mechanism (PLM) there was conducted an analysis of reliability indices [3, 11]: 1. mean life to the first failure (thous. km.); 2. confidence interval (thousand km.); 3. standard deviation (thous. km.); 4. variation coefficient; 5. Weibull parameter ***b***; 6. Weibull parameter ***a***; 7. gamma – percentile life at γ= 90% (to the first failure); 8. gamma – percentage life at the given value γ= 90% (to the second failure); 9. failure rate per given operating time t_1 = 30 thous. c. (to the first failure); 10. failure rate for the given operating time t_1 = 30 thous. c. (to the second failure); 11. Index $C_{pz}(t)$ of calculation methodology; 12. Index $C_0(\Delta t)$ of calculation methodology.

There were revealed main types of failures and malfunctions of PLM parts under specified operation conditions. There was calculated mean life of details, limiting platform lifting mechanism reliability, as mathematical expectation: $t_{co} = \frac{1}{N_0}\sum_{i=1}^{N_0} t_i$ thous. km, where t – run to limit state of the Ist element; N_0 – number of controlled elements.

For the approbation of failure models there was performed a statistic analysis and obtained main characteristics of the distribution by mean time between failures and run. On the basis of available data was made approximation of distribution functions: mean time between failures – by normal distribution law; for the run – by log-normal (Fig. 3).



/Time/ /Run/

Fig. 3. Approximation of distributions of the mean time between failures

Verification of compliance of general population sample characteristics showed that the experimental data on the distribution of parts life, limiting the PLM reliability are consistent with the theoretical Weibull laws of distribution and normal [12–15].

On the basis of the carried out analysis it follows that details life, limiting the reliability of the platform lifting mechanism, are within the 67–238 thous. kilometers and have variation coefficient of V = 0,27–0,77. Processing and analysis of statistical data, as well as the specific failures and malfunctions of parts, limiting the reliability, allowed to develop a chart of platform lifting mechanism reliability of MAZ dump trucks.

3. Assessment problem of optimal frequency of components diagnostic

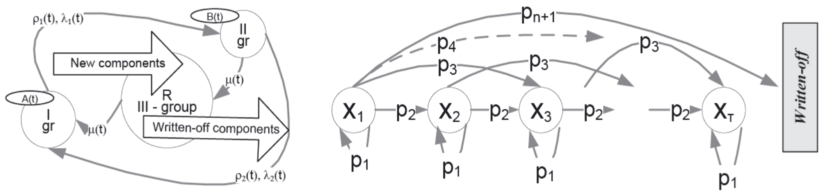
In order to determine optimal frequency of components diagnosis there was developed a model describing the change of operational status. A flow chart of this model is shown in Fig. 4.a. All components being in operation, were divided into three groups: the components satisfying the standards corresponding to operation season by their parameters (group I); components that remain functional, but not meeting current standards by their parameters (group II); components being repaired, new components, being prepared for use and components to be written off (buffer group III). The following indications were adopted in the model:

- $A(t)$, $B(t)$ – distribution of components due to the time in operation, respectively, in the I, II and III groups;
- $\lambda_1(t)$ – respectively rate of distribution and intensity of the flow of components transitions from the group I to the group II;
- $\lambda_2(t)$ – respectively rate of distribution and intensity of the flow of components transitions from the group II to the group I;
- $\mu(t)$ – flow rate of placing under repair or write-off and flow rate of putting new and renovated components into operation.

The analytical expressions for A(t) and B(t) were received both in the absence and in the presence of components reliability control system due to the condition. These solutions also describe part of components in pre-failure condition. This part depends both on the frequency of diagnosis and on the parameters of distribution laws for the probability functions being fundamental for $\lambda_1(t)$ and $\lambda_2(t)$. In its simplest form (without diagnostics), these expressions have the following form:

$$A(t)=A_0P_1(t),\ B(t)=B_0P_2(t)e^{-\mu t}. \tag{1}$$

The authors proposed an assessment model of the frequency of inspections of the brake discs in order to minimize the loss of resources and working time for their bore in accordance with statistical data (wear-out measurements) obtained on each specified ATE. Construction of the model was carried out using a known apparatus of graph charts describing a discrete set of states of the object with a particular set of functions and transitions between these states – peaks of the flow-chart (Fig. **4**.b). [16–18].



a) Distribution of technical condition **b)** Flow-chart of components states

Fig. 4. Markov model of the change of components states

As peaks were taken moments of time corresponding to the facts of machining of parts. At the same time in order to find functions of the transition between states (determined in each particular case for different parts) are required statistical data on changes in the technical state of details in real operating conditions, taking into account boundary conditions of the problem having an impact on adequacy of the description of the model, such as the spread of the values of the geometric parameters of new parts at the time of installation on the vehicle, its writing off, etc.

4. Diagnosis of the state of components and assemblies on the basis of hidden Markov chains

For the problem of identification of components, state it is suggested a model of hidden Markov chain, which allows classifying the state by indirect evidence on the basis of the accumulated statistics. The model represents a tuple **SMM = {S, V, λ},** where:

1. **S**={S_1, S_2,…, S_n} – number of states of the model, where N – number of states, q_t – current state at the moment of time t.

2. **V**={v_1, v_2,…, v_M} – alphabet of the observed sequence.

3. **λ**=(A, B, **π**), where A=||a_{ij}|| – probability transition matrix, a_{ij} =P[q_{t+1}=S_j | q_t=S_j], 1≤*i,* j≤N; B=||$b_j(k)$|| – distribution of probability of occurrence of symbols in the j-state, where $b_j(k)$=P[v_k | q_t=S_j], 1≤*j*≤N, 1≤*k*≤M; π_i=*P*[q_1=S_i], 1≤*i*≤N.

SMM generates the observed sequence: O_1, O_2,…, *O*, where OtOV, T – length of sequence.

The sequence generation algorithm suggested by authors supposes the following steps:

Step 1. Select the initial state q_1=S_i in accordance with the distribution π=(π_1,…, π_N).

Step 2. Set t=1.

Step 3. Select O_t=v_k according to the distribution b_j(k) in S_i state.

Step 4. Transfer the model to the new state q_{t+1}=S_j in accordance with the transition matrix ||a_{ij}|| taking into account the current state of S_i.

Step 5. Set the time t: = t + 1; go back to step 3, if t <T; otherwise – the end of the algorithm.

On the basis of the model the following problem is solved: Given the sequence observed O_1, O_2,…, O_T and model λ=(A, B, **π**).. It is necessary to calculate the P(**O**|λ) – the probability that the observed sequence was constructed specifically on the basis of this model.

Let us consider the type of counting the probability of occurrence of the sequence of observations for each possible sequence of states of the model on the example of one sequence of states Q={q_1, q_2,… ,q_T, }, where q_1 – initial state of the model. The probability of sequence occurrence **O** is $P(O \mid Q,\lambda)=\prod_{t=1}^{T} P(O_t \mid q_t,\lambda)$ where there is a statistical independence of observations. Probability of matching ***O*** and ***Q***, ie possibility of their simultaneous manifestations is expressed by

$P(O,Q\,|\,\lambda)=P(O\,|\,Q,\lambda)\cdot P(Q,\lambda)$. The probability of occurrence of ***O*** – is the sum of the probabilities for all possible combinations of states of q system:

$$P(O\,|\,\lambda)=\sum_{Q} P(O\,|\,Q,\lambda)\cdot P(Q,\lambda)$$

On the Fig. 5 it is shown the sample path of the hidden Markov chain of changes of component states generated according to the designed model.

To solve this problem it is suggested to use forward and reverse algorithms. At that $\alpha_t(i)$ is defined as $\alpha_t(i)=P(O_1,O_2,...,O_t,q_t=S_i\,|\,\lambda)$. That is the possibility that the given model λ at the moment time t was observed a sequence $\boldsymbol{O}_1$, $\boldsymbol{O}_2$,…, $\boldsymbol{O}_T$ and at the time t and the system is in the state S_i.

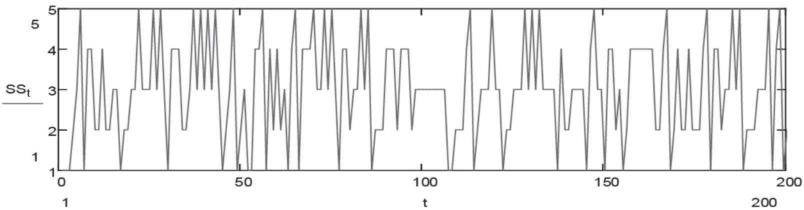


Fig. 5. Sample path of the hidden Markov chain of components states change

For searching the values of $\alpha_t(i)$ is suggested a recurrent scheme:

1) Initialization: $\alpha_1(i)=\pi_i b_i(O_1)$, $1\leq i\leq N$.

2) Induction: $\alpha_{t+1}(j)=\left[\sum_{i=1}^{N}\alpha_t(i)a_{ij}\right]b_j(O_{t+1})$, $1\leq t\leq T$-1, $1\leq j\leq N$.

3) Completion: $P(O\,|\,\lambda)=\sum_{i=1}^{N}\alpha_Y(i)$.

During the approbation the given algorithm has shown a sufficiently high convergence and low probability of misclassification.

5. Information Support System

To accompany data concerning registration, current state and record of repairs of the serviced equipment it is suggested to use information support system (Fig. 6). The system includes subsystems of registration of equipment lists, registration of data about the performed maintenance operation and repairs, as well as formation of reports on the current status and record of repairs of the serviced equipment.

The results of performing the procedure 1 are the lists of the serviced equipment registered in the information system. Incoming documents include a list of equipment to be repaired and subject to maintenance with basic requisites: customer, list of machines, etc. [19, 20].

The results of performing the procedure 2 are data on the current status and record of repair of techniques, registered in the information system. Incoming documents include act of completion of work with basic requisites: act number, date, order number, customer, repaired equipment, the list of parts actually used in the repair, actually performed work, actually incurred labor costs.

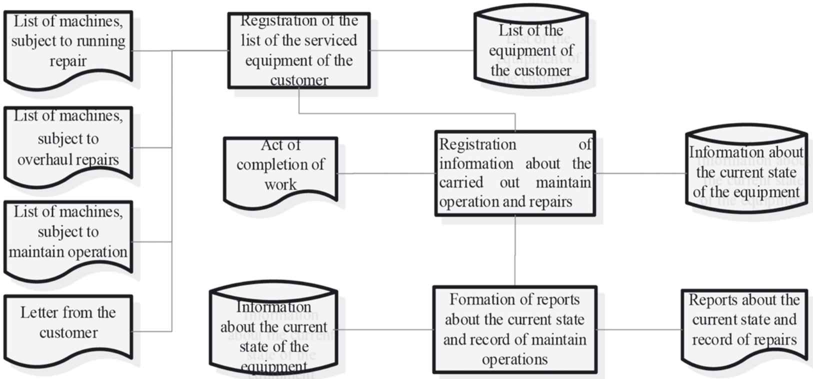


Fig. 6. Information support system

Procedure 3 of the formation of reports on the current status and repair record of the serviced equipment of regular customers include tabular and graphical forms in the information system concerning: machines, customers, dates, types of work, etc. Outbound documents include: customer, car mark, garage number, chassis number, endurance operating hours, the site made repairs, contract number, the date of execution of works, the number of act of completion, type of work (maintain operation, running repairs, overhaul repairs, etc.), the repaired system (engine, chassis, hydraulics, etc.), carried out works, performer of the works, the amount of work, installed parts, the sum on spare parts, purchased parts, parts manufactured in ATE, parts manufactured by the forces of subcontract organization.

6. Conclusion

The conducted statistical analysis of the flow of applications for parts, components and accessories of various groups and types of turnover from a number of transport enterprises allowed to reveal relationship between the different parts and groups of ATE. By the example of the platform lifting mechanism was carried out a research of the flow of failures of components and details of transport and technological machines, which allowed us to estimate the parameters of probability distributions for the models of formation of reserves in the maintenance and repair management systems. On the basis of hidden Markov processes were developed models of diagnostic and identification of the state of components and assemblies, allowing to identify the technical condition of equipment by indirect evidence. An original algorithm for generating the sequence of inspections was developed. It was suggested to use the information support system for the maintenance of data concerning registration, current status and record of repairs of the serviced equipment.

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