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The algorithm of modeling of receipt and service of orders processes with account of the necessity for compliance with warranty duration of repair

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Summary. In the article there is provided the description of the algorithm of modeling the process of receipt and service of incoming flows of orders for repair with an account of regularities of their emergence, that have been identified on the basis of the register books of orders of technical service enterprises, and with consideration of the need for compliance with warranty duration of relatively person belonging repair.

The initial data for the modeling are the following: parametric rows of production structures of processing lines (TL) or sections (TS) of repair of different annual performance Q_P, duration of the technological process of repair $T_{\text{т.п}}$, value of warranty duration of repair T_{Γ} and terms of compensation to the customers in case of non-compliance with this duration, range of variation of a value of the time reservation factor $\rho_T = 1 \ldots \rho_{T\max}$ (where $\rho_T = T_{\Gamma}/T_{\text{т.п}}$), and also the pattern of variation of annual repair program by years of exploitation of TL or TS $W_P = f(\mathrm{T})$.

The algorithm calls for implementation of five basic steps, namely: 1) selection of TL (TS) from the parametric row; 2) repeated reproduction process of receipt and service of orders for repair for each year of exploitation of TL (TS); 3) calculation of physical and techno-economic criteria of compliance with the T_{Γ} for direct and reverse sequences of orders fulfillment and for different values of the time reservation factor $\rho_T = 1 \ldots \rho_{T\max}$ based on the results of every such reproduction; 4) statistic analysis of the results of calculation of physical and techno-economic criteria of compliance with the T_{Γ} for each year of exploitation of TL (TS); 5) output of the results of statistic analysis for the whole period of exploitation of TL (TS).

Each of the abovementioned modeling phases is described in detail.

Application of the proposed algorithm will permit to choose TL (TS) from the parametric row and to substantiate the warranty duration of fulfillment of orders for repair T_{Γ} with an account of the objective variability of annual repair programs during the entire period of exploitation of TL (TS).

Key words: incoming flows of orders for repair, service, warranty duration of repair, modeling, algorithm.

INTRODUCTION

Modern methods of design of technical service enterprises should not only provide the identification of repair programs, and for multi-disciplinary enterprises - the correlation between separate programs,but also should they take into account the stochastic nature of receipt of orders for repair. The process of heads of cylinder blocks receipt for repair, as well as of receipt of any other aggregates is random and annual repair programs are variable by years.

Compliance with warranty duration of repair TΓ, which shall be determined in the services contract with the customer, is essential for efficient operation of enterprises of technical service. The factors that affect the compliance with the T_{Γ} in case of relatively person belonging repair are performance backup, time reservation and sequence of execution of orders: direct (*First In First Out - FIFO*) or reverse (*Last In First Out - LIFO*). The level of performance backup is objectively formed as the ratio of annual repair program in different years of exploitation of TL (TS) to their maximum annual productivity $\rho_N = W_P/Q_{P\max}$. Thus, two of the factors affecting the compliance with the warranty duration of repair are controllable, namely time reservation T_{Γ} and change of the sequence of orders execution.

Identification of the impact of these factors on the level of compliance with the warranty duration of repair T_{Γ} and on the enterprise's index of effectiveness in circumstances of variability of annual repair programs and of stochastic nature of daily batches of orders for repair is possible only through modeling. Thus the task of developing an appropriate algorithm of modeling and of its software implementation is relevant.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Analysis [1-4] of statistical properties of incoming flows of orders for repair revealed regressive dependences of average volume of batches of orders $M[\delta_i]$ and of index of variation $\nu[\delta_i]$ on annual program of repair W_P of an enterprise of technical service (Fig. 1), which are calculated by the following formulae:

$$M[\delta_i] = a_0 + a_1 \cdot W_p, \quad (1)$$

$$\nu[\delta_i] = b_0 + b_1 / W_p, \quad (2)$$

where: a_0, a_1 and b_0, b_1 are values of regression indices for different machines.

Writings [5-16] deal with ways of compliance with requirements as to warranty duration of repair. For the purpose of compliance with warranty duration of relatively person belonging repair of aggregates the criteria and factors which ensure the compliance with the duration of repair were substantiated. As such criteria were taken the following: the index of keeping the requirements of warranty repair duration, $\xi_N = W_N/W_P$, the average duration of over guarantee downtimes $\theta = \Sigma\theta_j / W_\theta$, where W_N is number of orders executed during the warranty period; $W_\theta = W_P - W_N$ is the number of orders for which warranty period of repair was exceeded.

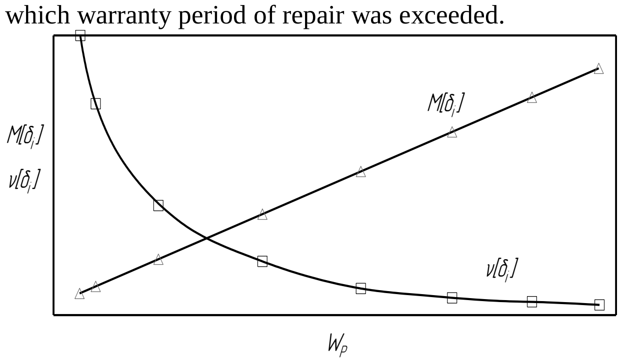

Fig.1. Patterns of formation of orders for repairs

As factors of compliance with the warranty duration of relatively person belonging repair were considered the following: performance backup, which was measured as the index $\rho_N = W_P/Q_P$; time reservation, which was measured by the index $\rho_T = T_\Gamma/M[T_{T.P}]$; changes in the sequence of service of orders (direct – *FIFO*, reverse – *LIFO*), where Q_P is annual performance pcs.; $M[T_{T.P}]$ is a value of the probabilistic mean of duration of the repair, days.

The nature of dependence of criteria of compliance with the warranty repair duration T_Γ for different values of ρ_N and ρ_T and for incoming flows of different regularity [1, 3, 6-15] was identified, optimal conditions of compliance with the T_Γ in case of irrelatively person belonging as well as relatively person belonging methods of repair of transmission units [2, 4, 5] were substantiated. However, the pattern of change of annual repair program by years of exploitation of TL or TS was not taken into account in these studies.

RESULTS

The aim of the paper is to develop the modeling algorithm of service process by process section (TS) with a given production structure of a variable by year of its exploitation stochastic input stream of orders for repairs of units or aggregates (by the example of heads of cylinder blocks of YMZ engines) with an account for the need for compliance with warranty duration of repair.

Based on statistical data the dependence of the probabilistic mean of the daily batch of receipt of heads of YMZ cylinder blocks for repair $M[\delta_{i\ YMZ}]$ on the annual program was identified:

$$M[\delta_{i\ YMZ}] = 1{,}4774 \cdot W_P. \quad (3)$$

The regression dependence of variation coefficient of the daily batch of receipt of heads of YMZ cylinder blocks on the annual program is obtained:

$$\nu[\delta_{i\ YMZ}] = 1{,}1868 e^{-0{,}038 \cdot Wp}. \quad (4)$$

For the modeling of receipt process and service process of orders for repair of heads of cylinder blocks of YMZ engines the algorithm, which consists of several blocks, was developed in Atom software (fig. 2).

The initial data for modeling were the following: parametric row of production structures of processing lines (TL) or sections (TS) of repair of various annual productivity Q_P (tab.), duration of the repair process $T_{т.п}$ (for heads of cylinder blocks $T_{т.п}$=1 day), value of the warranty duration of repair (T_Γ) and terms compensation to customers in the event of non-compliance with this duration 9 (taken for 3% of the cost of orders executed with delay), the range of variation of the time reservation factor values $\rho_T = 1 \ldots \rho_{T\max}$ (where $\rho_T = T_\Gamma/T_{т.п}$, $\rho_{T\max} = 10$) and also the pattern of change of annual repair program by years of exploitation TL or TS $W_p = f(\text{T})$.

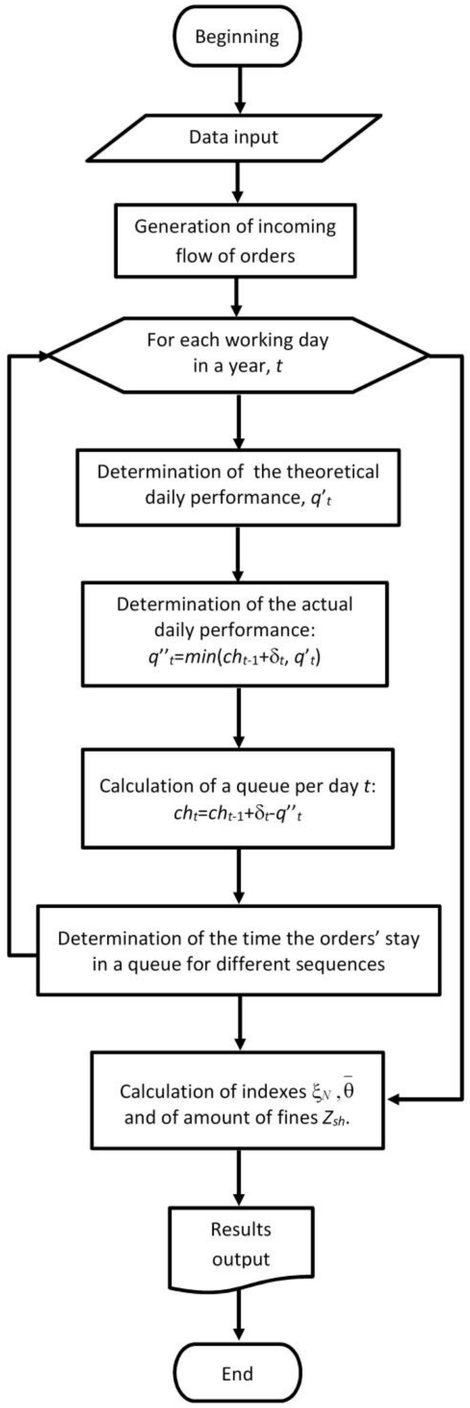

Fig. 2. Structure flow chart of the algorithm of inflows and service of orders for repair

Table. Parametricrowof production structures of processing lines of heads of cylinder blocks of engines YMZ-236 and YMZ-240 repair in united process flow (fragment).

No. TS	Annual per-formance Q_P, pcs.	Front of repair *f*, pcs.	Number of workers *u*, persons	Techno-logical cancellation (TC)	Amount of main equipment of various types, pcs.													*PZ*, UAH.
					Kr_1	Kr_2	Kr_3	Kr_4	Kr_5	Kr_7	Kr_8	Kr_9	Kr_{10}	Kr_{11}	Kr_{12}	Kr_{13}	Kr_{14}	
1	**391**	**1**	**1**	Direct flow	1	1	1	1	1	1	1	1	1	1	1	1	1	**497,11**
	427	2	2	Direct flow														534,06
2	391	1	1	Direct flow	2	1	1	1	1	1	2	1	1	1	1	1	1	537,81
	503	**1**	**2**	Ramified														**483,88**

In the first stage, on the basis of the pattern of change of annual repair program $W_P = f(\mathrm{T})$ and with the accepted value of the usage period TL (TS) $\mathrm{T}_{експл}$ such value of TL or TS is selected from the parametric row, for which the maximum performance Q_{Pmax} enables the execution of all the values of the annual programs of repair over a period $\mathrm{T}_{експл}$, where $\mathrm{T} = \overline{1, T_{експл}}$. That is, the condition $Q_{Pmax} \geq$ $\geq \max[W_P = f(\mathrm{T})]$ must be fulfilled.

The next block includes multiple reconstitutions of the process of receipt and service of orders for repair.

The parametric row is formed in such a manner, that for each TS with a constant production structure performance may vary depending on the number of workers involved *u*. Consequently, specific expenses for repair *PZ* will also vary for various performance values (tab.).

The theoretical daily performance q'_i TL (TS) per day *t* was calculated using the recursive algorithm*:*

$$\begin{cases} q'_t = \left[Q_p \dfrac{t}{T_p} \right] - Q'_{t-1}; \\ Q'_t = Q'_{t-1} + q'_t, \end{cases} \tag{5}$$

where: Q'_t is a theoretical performance over a period of *t* days from the beginning of the year (Q'_0=0).

Thus, on different days the performance will q' vary slightly, nevertheless in the end of the year the total $\sum_{t=1}^{T_p} q'_t$ will equal to Q_P. This technique makes it possible to operate with integer values of performance, which corresponds to the realities of production and simplifies the calculations in the model

In accordance with the annual program W_P the probabilistic mean $M[\delta_i]$ and the coefficient of variation $\nu[\delta_i]$ of a daily batch of orders for repair are selected and the simplest Poisson flow of orders is generated. There by the array Δ of orders is obtained, which consists of 252 elements $\Delta = \{\delta_1, \delta_2, \ldots \delta_{Tp}\}$, where *i* is a serial number of a working day an a year.

The array of queues $Ch = \{ch_1, ch_2, \ldots ch_{Tp}\}$, in which ch_1=0 is a value of a queue formed on the first working day of the year, is viewed. On other days $ch_i = ch_{i-1} + \delta_i$ the performance of the processing line, which will ensure the fulfillment of the whole amount of orders during the year, and also values of given specific technological expenses PZ_i (tab.) are selected from a preliminary formed parametric row according to the state of a queue ch_i on day *i*.

All orders on day *t* are fulfilled if:

$$ch_t + \delta_t \leq q'_t, \tag{6}$$

where: ch_t is a queue on day *t*, pcs.;

δ_t is a number of orders on day *t*, pcs.;

q'_t is daily performance on day *t*, pcs.

Otherwise, only q'_i number of orders are fulfilled and the queue for the next day forms:

$$ch_{t+1} = ch_t + \delta_t - q'_t \tag{7}$$

The next block displays the fulfillment of orders in direct (*FIFO*) and reverse (*LIFO*) sequences and also forms the queue of orders for repair of objects, which will be processed with delay.

The block of orders fulfillment in different sequences involves fulfillment of orders i_W under the condition that и $t_{vh.i} \to min$ for direct and $t_{vh.i} \to max$ for reverse sequence of fulfillment of orders from the array of values $T_{vh}\{t_{vh.1}, t_{vh.2}, \ldots t_{vh.Tp}\}$, moreover:

$$\begin{cases} t_{vh.i} \leq t_i, \\ t_{vyh.i} = 0, \end{cases} \tag{8}$$

where: i_W is a serial number of an order;

$t_{vh.i}$ is a serial number of a day of receiving an order;

$t_{vyh.i}$ is a serial number of a day of an order fulfillment.

There after the value of the index of meeting the requirements as to warranty duration of repair ξ_N and the average duration of over guarantee downtimes $\bar{\theta}$, which are determined for different values of the time reservation index $\rho_T \in [1\ldots10]$, have been calculated.

Orderswere considered to have been fulfilled in compliance with the warranty duration, if:

$$t_{vyh.i} - t_{vh.i} + 1 \leq \rho_t\,. \tag{9}$$

Otherwise, an order was considered to have been fulfilled with violation of the warranty duration of repair with delay:

$$\theta = t_{vyh.i} - t_{vh.i} + 1 - \rho_t > 0. \tag{10}$$

where: ξ_N and $\bar{\theta}$ for different values of ρ_T and for different sequences of orders fulfillment have been calculated.

In this block also the amount of fines Z_{sh} for orders fulfilled with delay, which will ultimately be added to specific expenses TL (TS), has been calculated

$$Z_{sh} = \sum t_{sh} \cdot 0{,}03 Z_{pr.teh.} \tag{11}$$

where: Σt_{sh} is a total number of over guarantee downtimes, days;

$0{,}03Z_{pr.teh.}$ is an amount of a penalty, paid to customers for the delay of services (3% of the expenses for fulfillment of orders, for which the $T_Г$ was violated), UAH.

Statistic analysis of the results of calculation of physical and techno-economic criteria of compliance with

$T_Г$ for each year of TL (TS) exploitation consisted in the determination of distribution parameters (the probabilistic mean, average quadratic deviation and the coefficient of variation).

For example, the coefficient of variation of the daily batch of orders for repair ν[δi] was calculated by the following formula

$$\nu[\delta_i] = \frac{\sigma[\delta_i]}{M[\delta_i]}, \quad (12)$$

where: σ[δi] is average quadratic deviation of daily batch of orders

$$\sigma[\delta_i] = \sqrt{D} = \sqrt{\frac{\Sigma\delta_i^2}{T_p} - \left(\frac{W_p}{T_p}\right)^2}, \quad (13)$$

where: D – is dispersion of a daily batch of orders.

$$M[\delta_i] = \frac{W_p}{T_p}, \quad (14)$$

where: T_p is a number of working days in a year; W_P is annual program of repair, pcs.

It follows that the coefficient of variation of daily batch of orders for repair is calculated from the expression:

$$\nu[\delta_i] = \frac{\sqrt{T_p \cdot \Sigma\delta_i^2 - W_p^{\ 2}}}{W_p}. \quad (15)$$

According to the results of modeling, the value ν[δi] for repair of heads of cylinder blocks of YMZ-236 engines has been obtained and amounts to $\nu[\delta_{i\_236}]\in[0,8\ldots2,6]$, for YMZ-240 engines the obtained value amounts to $\nu[\delta_{i\_240}]\in[0,8\ldots1,7]$, and also for the case of their repair in a common flow this value amounts to $\nu[\delta_{i\_\Sigma}]\in[0,8\ldots0,9]$, that corresponds to the theoretical modelν[δi]= $f(W_P)$ (fig.3).

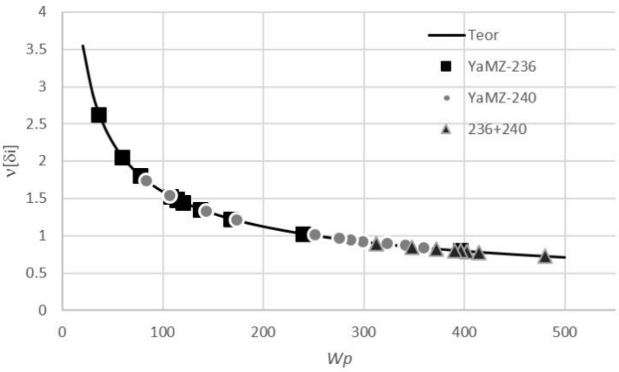

Fig. 3. Dependence of the variation of a daily batch of orders for repair on the value of the annual program of repair

The last block of the algorithm is the block of results output. For convenience, the results are displayed in a tabular form (Fig. 4), which allows further statistic analysis and graphical interpretation

A special feature of the algorithm is the possibility to carry out the modeling of receipt and service of orders for repair of different objects on separate processing lines as well as in united process flow.

Part number	Reception day	Release day *FIFO*	Release day *LIFO*
1	105	107	105
2	128	134	128
3	235	246	235
4	168	181	168
5	226	239	226
6	74	76	74
7	147	159	147
8	221	230	221
9	87	87	87
10	93	94	93
11	83	83	83
12	117	118	117
13	125	129	125
14	137	143	137
15	163	176	163

Day	Number of orders	*q'*	Executed orders	Turn
1	6	1	1	5
2	2	2	2	5
3	0	1	1	4
4	2	2	2	4
5	2	1	1	5
6	0	2	2	3
7	1	2	2	2
8	1	1	1	2
9	2	2	2	2
10	0	1	1	1
11	1	2	2	0
12	0	1	0	0
13	2	2	2	0
14	4	2	2	2
15	0	1	1	1

ξN FIFO	Θ FIFO	Zsh FIFO	ξN LIFO	Θ LIFO	Zsh LIFO	ν
0.5221	1.5689	4357.408	0.8034	3.7856	4283.312	0.7953

Fig. 4. Presentation of modeling results (fragment)

CONCLUSIONS

1. The developed algorithm will make it possible to model the flow and service of orders for repair with account of the objective variability of annual repair program and also of the need for meeting the requirements as to the warranty duration of repair in accordance with the actual conditions of work of enterprises of technical service.

2. The developed algorithm and software for its implementation are universally applicable, since they provide an opportunity to consider different patterns of change of annual repair programs and also parametric rows of production structures of processing lines or sections of various performance, which have been formed by drawing upon the results of structural and parametric analysis and synthesis of technological processes of repair of various objects.

3. The use of the developed algorithm makes it possible to choose the processing line or section from a pre-formed parametric row and to substantiate the warranty duration of repair in post-warranty period.

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АЛГОРИТМ МОДЕЛИРОВАНИЯ ПРОЦЕССОВ ПОСТУПЛЕНИЯ И ОБСЛУЖИВАНИЯ ЗАКАЗОВ С УЧЕТОМ ПОТРЕБНОСТИ СОБЛЮДЕНИЯ ГАРАНТИЙНОЙ ПРОДОЛЖИТЕЛЬНОСТИ РЕМОНТА

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Аннотация. Приведено описание разработанного алгоритма моделирования процессов поступления и обслуживания входящих потоков заказов на ремонт с учетом закономерностей их формирования, выявленных на основании книг регистрации заказов предприятий технического сервиса, и потребности соблюдения гарантийной продолжительности ТГ необособленого ремонта.

Ключевые слова: входные потоки заказов на ремонт, обслуживание, гарантийная продолжительность ремонта, моделирование, алгоритм.