Predictive Model of the Organization of Car Maintenance and Repair Wagons using the Smoothing Algorithm the Extrapolation Method

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Abstract: When developing a predictive organizational model for the maintenance and repair of railcars at large marshalling yards, we take into account the multi-factor composition of variable values, many of which should be within the required values without disrupting the order and activity of the transportation process. In such cases, additional justification is required for the technical decisions taken to ensure normal and safe operating conditions. The article provides a methodology for substantiating technical solutions for improving the organization of car maintenance by determining forecast values for a given time interval. The list of measures to improve the system within the framework of the selected factor is considered: installation of floor-standing equipment in the form of an additional service channel for monitoring the sub-car space, installation of SPIDER-type diagnostic equipment to provide an assessment of the technical condition of the car according to external parameters. The effectiveness of implemented measures was evaluated.

1 INTRODUCTION

Along with the increased demand for freight transportation, there was a problem associated with the development of a set of tasks, the solution of which will optimize the operation and increase the efficiency of the use and operation of railcars. One of these tasks is the development of up-to-date regulatory and technical documentation for the design of maintenance and repair technology. The analytical solution of the problem is complex (Zubkov, 2022; Zubkov, 2022; Zubkov, 2022; Pershin, 2021), and in some cases is hardly feasible. Modern approaches to solving such problems actively use numerical modeling methods, in particular the extrapolation method (Yushkova, 2021; Galkin, 2021; Zubkov, 2021; Zubkov, 2021; Kamaretdinova, 2020). The article describes the process describing the dynamics of restoring the service life of railcars in the framework of maintenance and repair of freight cars with various types of technical malfunctions. The restoration process consists of preliminary decisions on the regulations and content of the necessary work to be performed in order to increase the efficiency of production of the car industry. A unified and adapted structural model for decision-making development is presented in figure 1.

The description of each block according to the scheme shown in Figure 1 is defined as follows:

Block 1 is responsible for forming an informative block that includes the results of an analysis of situations that arise in the divisions of the car industry with a problem statement based on the multi-factor structure of events that occur, for example, at the point of maintenance and current uncoupling repairs.

Block 2 is aimed at forming a target function with setting critical parameters and conditional restrictions, for example, increasing the efficiency of production of restoring the technical resource of wagons in conditions of limited time and parameters of maintenance and repair.

Block 3 determines the performance of work related to the collection and analysis and identification of the informative component of the car farm division, as well as operational processing of the obtained statistical data with subsequent evaluation using known methods, for example, extrapolation and fixing the distribution law of a random variable, in order to predict the time interval for the desired period under given conditions.

Block 4 based on the forecast values of the

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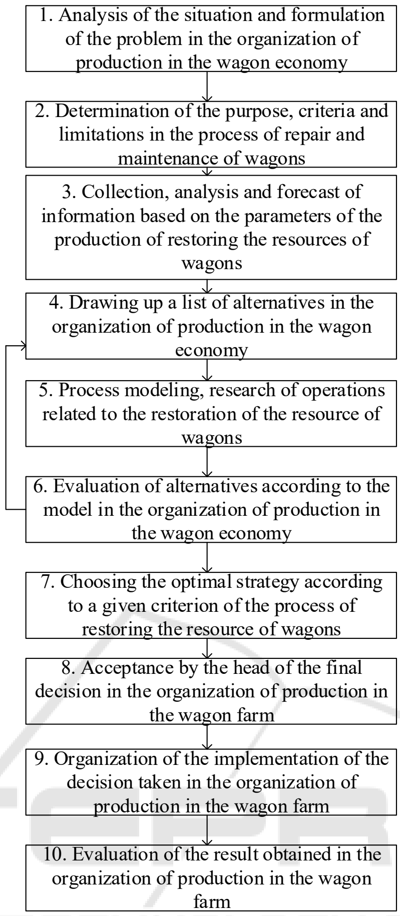


Figure 1: Decision making scheme.

multi-factor component of the car industry divisions, a selection of the most dangerous factors affecting the reduction of production efficiency is made.

Block 5 processes the obtained indicators in block 4 by superimposing them on the mathematical model of queuing with the introduction of variable values, coefficients of alignment of future indicators for a given time interval.

Block 6 evaluates alternative solutions based on the model. Thus, the inverse problem of finding effective tools for influencing current indicators is solved, and a stochastic value of possible deviations from the desired target function is laid. If the desired indicators remain unchanged from the initially set forecast parameters, the process returns to block 4. The cycle of this process is repeated until the target function is reached to the desired state.

Block 7 selects the optimal set of influence coefficients, which ultimately determines the optimal strategy for a given criterion.

Block 8 at the stage of the current block, using expert assessment methods, the manager makes a number of strategic decisions to choose the optimal one, among the indicate dones. In some cases that are particularly dangerous to security and cost-effective, a pre-completion block is performed aimed at developing a pilot project with an assessment of bottlenecks.

Block 9 performing organizational and technical work to implement the selected (from block 8) strategic solution.

Block 10 performing an evaluation of the result obtained that meets the criteria of economic efficiency and safety criteria.

Based on the above, to assess the impact of maintenance and repair on the technical condition of rolling stock when performing work, the extrapolation method and the queuing method were used for predictive assessment and indicative assessment, respectively. The article uses blocks 1-3, so that the calculation is performed in the Excel software package.

After setting the problem and determining the goal of the solution, an important component of the process of finding optimal strategies (strategic decision) is the collection, analysis and forecasting of information (block 1-3).

The main forecasting methods used in the railcar industry are methods based on dynamic series. A dynamic series is a sequence of numerical values that characterize changes in a process over time. When analyzing the dynamics series, statistical data collected over a certain period of time are used to determine the nature of the direction and intensity of quantitative changes in processes. Distinguish between the level of a series and a trend. Row level – a member of the dynamics row. Trend – the main deterministic trend of process change. The levels of a series are considered as random variables that change over time depending on the main and random factors.

Forecasting – determining the probable state of the process in the future. It is complicated by the presence of areas of gradual, evolutionary development, areas of abrupt, revolutionary development, and factors that cause actual levels to deviate from the trend. In forecasting, the process of changing a variable is expressed by a general model:

$$y(t) = f(t) + \varepsilon(t), \tag{1}$$

where $y(t)$ is the production parameter under study (the volume of production of cars with maintenance and/or PTOR, the volume of cars that have passed maintenance, etc.);

$f(t)$ - trend, regular component.

$\varepsilon(t)$ - random component.

Trends are determined by numerous methods: extrapolation method, queuing method, etc. Extrapolation is understood as the spread of patterns, relationships and relationships that operate in the studied (past) period, beyond its limits (in the future). The queuing method is understood as a closed system with its existing service channels (personnel, equipment, etc.) that perform the main list of works and requests received for service (products, rolling stock, visitors, etc.) with which or on which work is being carried out to restore the resource and other types of work that resemble maintenance.

2 MATERIALS AND METHODS

2.1 Initial Data

One-step smoothing algorithm

1. The original dynamic series is formed from statistical data for a certain period of time and recorded as a table. We will conduct a study of the implementation of forecasting changes in the performance of maintenance and repair at the point then the current uncoupling repair. Related data are available for the period from 2019-2021 -2021 г.г, Table 1.
2. In accordance with the experimental data, one or more functions are selected for the procedure of smoothing equations. Experimental data show that labor productivity changes with time in an approximately linear manner. Therefore, we choose a linear function of the form 2 as a model for smoothing and forecasting:

$$\bar{v}(t) = a_0 + a_1 t, \tag{2}$$

2.2 Design Equations and Boundary Conditions

We determine the numerical values of the regression coefficient estimates by forming systems of normal equations using the least squares method. For this purpose, we substitute the parameter $\tilde{y}(t)$ in equation 2 instead of the parameter ỹ (t).

As a result, we get:

$$F = \sum_{t=1}^{n} (v_i^2 - 2v_i \bar{v}_i + \bar{v}_i^2) =$$

$$\sum_{t=1}^{n} (v_i^2 - 2v_i a_0 - 2v_i a_1 t + a_0^2 + 2a_0 a_1 t + a_1^2 t^2) \Rightarrow \min.$$

To find the extremum of the function, we equate the first partial derivatives of the objective function with respect to the corresponding unknowns to zero, obtaining a system of normal equations for finding the unknowns a_0, a_1

$$\frac{\partial F}{\partial a_0} = 0, \ \ n a_0 + a_1 \sum_{t=1}^{n} t = \sum_{t=1}^{n} v_i ;$$

$$\frac{\partial F}{\partial a_1} = 0, \ \ a_1 \sum_{t=1}^{n} t + a_1 \sum_{t=1}^{n} t^2 = \sum_{t=1}^{n} y_i t.$$

To solve this system of equations, we apply the matrix method $X = A^1 B$

$$\lambda = \begin{bmatrix} a \\ a_1 \end{bmatrix}, \ \ A = \begin{bmatrix} n & \sum_{t=1}^{n} t_1 \\ \sum_{t=1}^{n} t_1 & \sum_{t=1}^{n} yt \end{bmatrix}, \ \ B = \begin{bmatrix} \sum_{t=1}^{n} y_i \\ \sum_{t=1}^{n} vt \end{bmatrix}.$$

where

Table 1: Dynamic series for restoring the service life of faulty railcars

Map items	Rolling stock													Enlarged car units					Details of railcars			
Time intervals	Restoration of the technical life of railcars in the amount of unplanned repairs			Trouble shooting of rolling stock components										Digressions in current uncoupling repair of wagons of enlarged car elements					Digressions in current uncoupling repair of wagons of the running parts of the car			
Indicators that determine the degree of development of factors	Number of defective freight cars in BOR	Number of defective freight cars in TR-1	Number of defective freight cars in TR-12	Disabled brakes restored	Replaced sets of air distributors	Replaced auto	modes Replaced autoregulators	Replaced рукавовR-17 hoses	Replaced end and release valves	Replaced brake pads	Replaced details auto coupler parts	Adjusting the brake lever gear	Other malfunctions	Bodywork	Frame	Auto coupler	Running gear	Brake system	Box node	Wheel crack	Side frame cracks/defects	Over the Spring beam crack
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
2019	455679	343	6200	986	652	18	23	201	211	17 267	397	5843	2796	38	21	13	125	6	1	1	1	11
2020	428158	667	6246	699	198	9	17	284	299	25 883	578	7985	3414	39	14	24	217	6	1	2	3	0
2021	377848	584	4932	269	117	10	7	407	430	38 806	848	11197	4341	41	2	46	94	56	3	15	29	21

The solution of the system was carried out using Excel software tools.

3 RESULTS AND DISCUSSION

As a result of the calculation using the method described above, prediction distributions are obtained using the extrapolation method. Figure 2 shows an example of the distribution of the forecast estimate of failures in the technical condition of railcars in the period from 2019-2021.

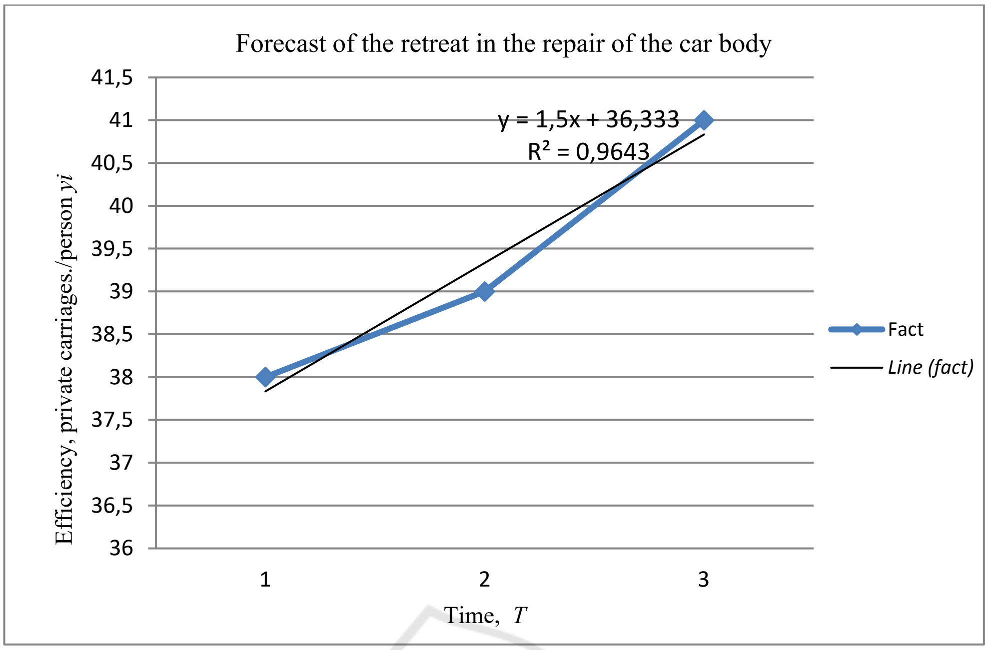
Calculations show that the forecast estimate of the output of cars with technical malfunctions does not exceed the indicator of more than 450 cars per year. Table 4 shows the results of calculating the projected number of railcars released from the TOP for the period from 2022 to 2027. figure 3.

Let's make a simulation based on Table the values of estimated factors specified in Table 1for the period from 2019-2021.we get the following results:

To solve this system of equations, the matrix method *X=A*^{1}*B is applied*

where
$$A = \begin{bmatrix} 3 & 6 \\ 6 & 14 \end{bmatrix}.$$

The values of the vector of free values X for matrix B are presented in Table 2.



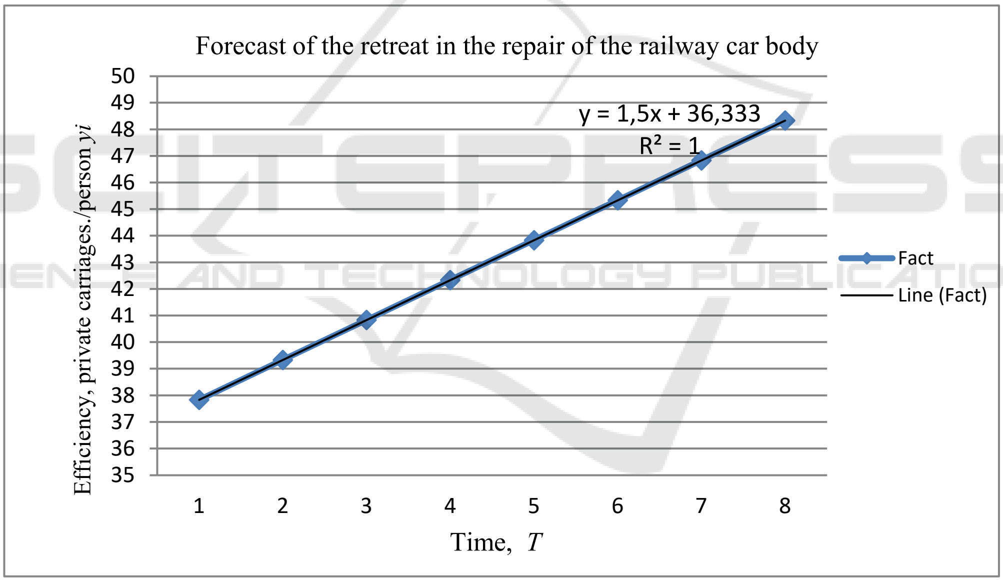


Figure 2: Results of calculating the dynamic series of the distribution of body part failures: top - in the period from 2019-2021-2021 г.г.; bottom-forecast for the period from 2022-2029.

Table 2: Calculated values of unknowns

y_i	1 261 685	1 594	17 378	1 954	967	37	47	892	940	81 956	1 823	25 025	10 551	118	37	83	436	68	5	18	33	32
v_t	2 445 539	3 429	33 488	3 191	1 399	66	78	1 990	2 099	185 451	4 097	55 404	22 647	239	55	199	841	186	12	50	94	74
a	498 392	290	7060	1368	857	20	32	91	94	5779	156	2987	1972	36	31	-5	176	-27	-0	-8	-17	1
a	-389	120	-634	-358	-267	-4	-8	103	109	10769	225	2677	773	2	-1	17	-1	25	1	7	14	5

Table 3: Forecast values

t		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		459 477	411	6 427	1 010	590	16	24	194	204	16 549	382	5 665	2 745	38	22	11	161	-2	1	-1	-3	6
2		420 562	531	5 793	651	322	12	16	297	313	27 319	608	8 342	3 517	39	12	28	145	23	2	6	11	11
3		381 646	652	5 159	293	55	8	8	400	423	38 088	833	11 019	4 290	41	3	44	130	48	3	13	25	16
4		342 731	772	4 525	-66	-213	4	0	503	532	48 858	1 059	13 696	5 062	42	-7	61	114	73	4	20	39	21
5		303 815	893	3 891	-424	-480	0	-8	606	642	59 627	1 284	16 373	5 835	44	-16	77	99	98	5	27	53	26
6		264 900	1 013	3 257	-783	-748	-4	-16	709	751	70 397	1 510	19 050	6 607	45	-26	94	83	123	6	34	67	31
7		225 984	1 134	2 623	-1 141	-1 015	-8	-24	812	861	81 166	1 735	21 727	7 380	47	-35	110	68	148	7	41	81	36
8		187 069	1 254	1 989	-1 500	-1 283	-12	-32	915	970	91 936	1 961	24 404	8 152	48	-45	127	52	173	8	48	95	41

The obtained values form exponents of a polynomial that allow us to determine the linear distribution law of a random variable for each factor indicated in Table 1.

Thus, it is possible to estimate the influence of the factor on the technical condition of rolling stock for several years in advance, the results obtained according to linear distribution laws CB They are represented by Table 3.

Negative values in the tables indicate the absence of a factor for the specified parameters of treatment and repair of compositions, values that increase over time in dynamics indicate the need to evaluate alternatives according to the model.

Further studies are the implementation of blocks 4-10, the research consists in the selection of factors that expose the organization of production of repair and maintenance of wagons in the forecast interval to a decrease in the efficiency of divisions. The obtained values will be used as variable values embedded in the mathematical queuing model, as well as equalization coefficients for future indicators for the period from 2023-2029. The model will be aimed at identifying the values of possible deviations from the desired objective function, the purpose of which is to select the optimal set of influence coefficients that do not threaten safety and economic efficiency according to the decision made.

4 CONCLUSION

Based on the results of the work performed, the following conclusions can be drawn:

1. It is revealed, that the basis of production management in a car maintenance depot is to make a strategic decision.
2. It is determined, that a strategic decision consists of a number of proactive measures combined into a decision-making scheme.
3. It is established that one of the first stages of numerical evaluation of proactive impacts on decision-making in the production organization is a forecast.
4. It is determined that the forecast estimation is performed using methods of extrapolation of data-based indicators of the queuing method to the HFE.
5. It is revealed that the forecast estimate for the next five years does not exclude the need to make a decision on increasing the capacity of the station with the introduction of modern maintenance and repair technologies.

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