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Opportunities to Increase Efficiency of Locomotives' Operation



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ABSTRACT

The article contains the analysis of statistics of locomotives' operation and define main opportunities to increase its efficiency. The main objective of the study is to reveal factors influencing the increase in reliability of locomotives.

Data of the sample of 40 locomotives of main series operated in Russia for the period of 400–500 days are used, which ensures accuracy of results obtained. The method of the study is mainly statistical processing of data. Besides commonly statistically analyzed positions like «in operation» and «faulty» new positions «at the head of the train» (effective work) and some other are considered. The coefficient of useful (effective) work is introduced. As a result, it is proved that feasible level of value-added use of locomotive up to 75 % of total time versus 49 % nowadays is possible. It is shown that reduction of time and cost of technical maintenance and repair of locomotives (TMR) is an important opportunity to increase efficiency of locomotives' operation. Besides, it has been proved that one of the reasons of over-downtime of locomotives under repair is a significant volume of violations of operating modes, which is also confirmed by statistical data used in previous publications.

Keywords: *transport, railway, locomotive, efficiency of locomotives' operation, technical maintenance and repair, violations of operating modes, algorithmic protection.*

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For the original Russian text of the article please see p. 82.

Introduction

Growing efficiency of locomotives' operation is among most significant components of the process of increasing haulage activity efficiency of a railway rolling stock operating company. To identify main opportunities to obtain more efficient use of rolling stock it is necessary to update methods of processing of statistical data on the operation of locomotives, to develop methods of evaluation of recommendations on the reliability, and, consequently, on the efficiency of operations.

The authors suggest to this end the results of a study which is based on the *methods* of statistical analysis of data on operation of locomotives of main models used in Russia by JSC Russian Railways. The main *objective* is to reveal the factors leading to increased reliability of locomotives' operation.

1. Efficiency of locomotives' operation: initial data and application of the methods of statistical analysis

In the information system of automated traffic operations management (hereinafter called ASOUP) of JSC Russian Railways [1] the operation of locomotive fleet is fixed along other parameters of transportation process. The authors performed analysis of these data to identify reserves to increase efficiency of the use of locomotive rolling stock. To ensure accuracy of findings about efficiency of locomotives' use representative sample of the most mass series of locomotives was selected that included electric locomotives VL10, VL80R, VL80S, VL85, 2(3) ES5K, 2(3) ES4K, diesel locomotives 2(3) TE10MK and 2TE116U. For each series, the data on 40 locomotives were retrieved from ASOUP, which made a statistically reliable (representative) sample, formed randomly. For each locomotive data on 400–500 days of operation from May 2017 until October 2018 were selected. The total number of initial data are equivalent to about 5 mln events. Processing of data is carried out using the program using the algorithmic language Visual BASIC for Applications (VBF) in Excel environment (more details on algorithmic language are proposed in e.g. [2]), specially developed by the authors. Preliminarily using three sigma rule [3, p. 67] artefacts referred to locomotives, which have been in reserve for a long time or under unscheduled repairs, had been deleted from samples. As a result, for some series the number of locomotives under consideration reduced from $N = 40$ to $N = 38$.

In ASOUP data on operation of locomotives are classified, for which more than 100 codes of state are used, particularly «locomotive at the head of the train», «service at planned technical maintenance of locomotives», «waiting for work», «waiting for second technical maintenance (or current repair-1, current repair-2 and etc.)», «waiting for repair», «wheel sets turning», «preparation for repair at a plant», etc. All these states are usually divided into two groups: «healthy state» and «defective state». Based on this, coefficient of technical readiness (CTR) or coefficient of readiness for operation (CRO) are introduced, which enable to assess general efficiency of locomotives' use. There are also many losses when a locomotive is operable since useful work is carried out by main-line locomotives mostly in the state «locomotive at the head of the train». All other states, according to terminology of methods of Lean Production and Toyota Production System [4–6] should be attributed to the losses of the first (can be eliminated immediately) and the second kind. In this regard, it is proposed to introduce an indicator «coefficient (per cent) of useful work» C_{uw}:

$$C_{uw} = T_{traction}/\sum T_i, \quad (1)$$

or

$$C_{uw} = 100\,\% \cdot T_{traction}/\sum T_i, \quad (2)$$

where $T_{traction}$ is the time during which the locomotive stays in the state «locomotive at the head of the train»;

$\sum T_i$ is total time of locomotive life cycle for the period under consideration.

For the samples of N locomotives for each series classic statistical parameters are calculated: mathematical expectation of coefficient C_{uw}, its root-mean-square deviation σ, coefficient of variation C_v, minimum *Min* and maximum *Max* values. According to Pearson criterion an indicator χ^2 and probability P of correspondence to the normal distribution law of a random variable, which is considered as a feature of unimodality of data: according to the law of large numbers unimodal samples tend to normal distribution, and the volume of sample allows to use this law. The main results are shown in Table 1.

2. Locomotives' operation efficiency: main results and TMR factor

The performed analysis showed that on average coefficient (per cent) of useful work is $C_{uw} < 50\,\%$. For electric locomotives coefficient

Table 1

Statistics of useful work of locomotives per series

Series/ Parameter	Sample, N	Coefficient of useful work, C_{uw}	RMS deviation, σ	Coefficient of variation, C_v	Min. value, Min	Max. value, Max	Pearson criterion, χ^2	Probability of correspondence, P
VL10	40	40 %	13	0,3	8 %	52 %	42,5	0,000
VL80S	40	53 %	14	0,3	18 %	73 %	8,7	0,050
VL80R	39	65 %	5	0,1	53 %	73 %	7,4	0,100
VL85	39	71 %	4	0,1	61 %	76 %	19,9	0,000
2ES5K	40	44 %	13	0,3	16 %	71 %	3,3	0,500
3ES5K	39	66 %	8	0,1	29 %	76 %	290,3	0,000
2ES4K	40	33 %	11	0,3	5 %	50 %	8,1	0,050
3ES4K	40	51 %	7	0,1	34 %	58 %	23,1	0,000
2TE116U	40	40 %	11	0,3	15 %	57 %	11,8	0,010
2TE25KM	40	41 %	7	0,2	24 %	49 %	14,5	0,001
2TE10MK	40	34 %	12	0,4	14 %	57 %	8,0	0,050
3TE10MK	40	37 %	13	0,3	5 %	55 %	13,5	0,001
On average		48,1 %				76,2 %		

C_{uw} is significantly higher. The results obtained are not unimodal, the reason is associated with different conditions of locomotives' operation during the year. Data for locomotives of series 2ES5K ($P = 0,5$), involved in local work and as road switchers, are relatively unimodal. Operation of locomotives of series VL85 (71,4 % with maximum 76,2 %) is the most efficient. We should highlight the reliability of the finding, since for each of 40 locomotives of each series the period of 400–500 days of their operation is considered. Therefore, coefficient of locomotives' use C_{uw} = 75 % should be accepted as a target indicator.

The traditional indicator, which characterized efficiency of locomotives' operation is daily average run. The calculation showed that correlation of this indicator with coefficient of efficiency C_{uw} is r = 0,993, that is almost equal to 100 %. Thus, it is enough to consider one of these two parameters. At the same time parameter of coefficient of efficiency is more convenient since it allows to compare efficiency of traction work for various series of locomotives in different regions and at different sites.

The authors considered losses of useful time of locomotives. One of main sources of losses is waiting for work in healthy state, which exceeds 10 % of time of useful work and for individual series it reaches 40 %.

The important reserve to increase coefficient of useful work C_{uw} is to increase efficiency of technical maintenance and repair of locomotives (TMR). We can consider an integrated indicator

Table 2

Statistics of time of TMR in total time budget of the locomotive

Series/ Parameter	Sample, N	Coefficient of useful work, C_{uw}	RMS deviation, σ	Coefficient of variation, C_v	Min. value, Min	Max. value, Max	Pearson criterion, χ^2	Probability of correspondence, P
VL10	39	13 %	6,6	0,5	2 %	31 %	14,70	0,001
VL80S	38	10 %	3,7	0,4	4 %	20 %	4,70	0,300
VL80R	39	11 %	2,1	0,2	7 %	15 %	1,70	0,700
VL85	39	10 %	1,9	0,2	6 %	14 %	2,20	0,700
2ES5K	39	10 %	4,6	0,4	3 %	20 %	6,70	0,100
3ES5K	40	10 %	3,7	0,4	5 %	18 %	10,80	0,020
2ES4K	40	17 %	6,9	0,4	5 %	37 %	5,40	0,200
3ES4K	39	12 %	5,2	0,4	6 %	26 %	10,80	0,020
2TE116U	39	19 %	6,4	0,3	8 %	34 %	2,10	0,700
2TE25KM	39	15 %	4,2	0,3	7 %	24 %	7,80	0,050
2TE10MK	40	20 %	7,3	0,4	5 %	37 %	2,30	0,500
3TE10MK	40	25 %	9,5	0,4	10 %	52 %	6,00	0,100

Table 3

Statistics for types (volumes) of TMR

Series/ indicator	Share of TMR in time budget	Percentage of time for various types of TMR in total time budget without taking into account waiting				
		Technical maintenance-2	Current repair-1	Current repair-2	Current repair-3	Unscheduled repair
VL10	8 %	14 %	74 %	3 %	3 %	6 %
VL80S	4 %	29 %	46 %	4 %	5 %	16 %
VL80R	5 %	31 %	35 %	5 %	5 %	24 %
VL85	6 %	27 %	37 %	7 %	10 %	19 %
2ES5K	3 %	45 %	28 %	3 %	8 %	15 %
3ES5K	3 %	36 %	35 %	6 %	12 %	12 %
2ES4K	5 %	37 %	37 %	1 %	9 %	16 %
3ES4K	55 %	15 %	45 %	8 %	15 %	17 %
2TE116U	4 %	21 %	16 %	14 %	13 %	36 %
2TE25KM	3 %	39 %	25 %	21 %	0 %	15 %
2TE10MK	7 %	19 %	32 %	7 %	6 %	36 %
3TE10MK	10 %	17 %	22 %	10 %	2 %	49 %
On average	5 %	28 %	36 %	7 %	7 %	22 %

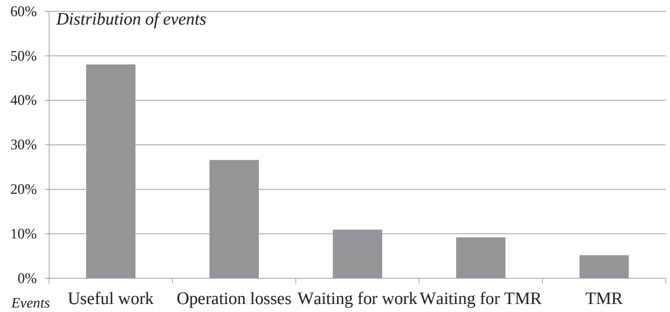
as a percentage of stay of locomotives in all states, related to TMR (Table 2) with statistical indicators similar to Table 1.

Unimodality of data according to Pearson criterion χ^2 is sufficiently expressed for locomotives of alternating current of old series: VL80 and VL85 with simultaneously low coefficient of variation C_v. For new series 2(3) ES5K adjustment of technological processes of technical maintenance and repair continues, therefore the process is multimodal. For diesel locomotives and electric locomotives of direct current unimodality is practically absent, which relates to the presence of over-cycle works and unscheduled repairs. This is evidenced by high coefficient of variation C_v. According to the calculation results, percentage of time for TMR significantly exceeds the calculated level (5 %), which is set as a target in the perspective plan of development of JSC Russian Railways [7, p. 42] and is within the range from 11,6 to 37,1 %. The lowest downtime for TMR is for electric locomotives of alternating current (10,5 %). There are individual locomotives with average annual downtime for maintenance of less than 5 %, and these are electric locomotives of series VL80S (4,1 %), 3ES5K (4,7 %) and VL10 (2,5 %). The indicator of series 2ES4K (5,1 %), 3ESK (5,8 %), 2TE10MK (5,4 %) is close to 5 %. Therefore, reduction of downtime for electric locomotives of alternating current to 5 % is possible. Downtime for technical maintenance and repair affects significantly average daily run of locomotives: correlation coefficient r = -0,87. For diesel locomotives downtime of new series for TMR is higher than the set one, but is significantly lower than for old series: 2TE116U (18,5 %), 2TE25KM (14,9 %).

The calculations showed big losses when waiting for repair: from 5 to 19,6 %. In the state «defective» waiting is on average 58 %. Only due to reduction of downtime when waiting for maintenance it is possible to reduce losses for TMR almost twice, it requires logistics discipline and not capital expenses. Table 3 shows losses for various types of TMR. TMR itself is equal to approximately 5,2 % of losses of $\Delta C_{uw,}$ but together with waiting for TMR the losses are of 14,4 %. The main share (85,2 %) in TMR refers to technical maintenance-2 (27,5 %), current repair-1 (35,9 %) and unscheduled repair (21,8 %). The authors' analysis allowed to conclude that it is possible to reduce downtime of locomotives for TMR twice. So, the improvement in the system of technical maintenance and repair is among the factors, complying with the objectives of the study.

Pic. 1 shows distribution of locomotive life cycle time at the stage of their operation. The data confirms the conclusion that TMR has important reserves to increase the efficiency of operation.

It is evident, that the TMR time and costs are influenced by violations of operation mode (VOM), which is considered in authors' papers, e.g. [8]. The authors after analyzing



Pic. 1. Average distribution of time budget of locomotives.

the repairs after VOM, developed a set of algorithmic protection measures, preventing faulty behavior of locomotive teams during operations [9]. The implementation of those algorithms in software of microprocessor locomotive control systems will allow to significantly increase the reliability of locomotives.

Conclusions.

1. The indicator traditionally used in Russia to evaluate the operation efficiency of locomotives is the average daily mileage. The calculations showed high correlation of that indicator with the coefficient of useful work C_{uw} (r = 0,993) that allows to choose between those two indicators. Hence, C_{uw} is more comfortable to be used as it allows comparisons of different locomotive series in different regions and at different sites.

2. The use of suggested coefficient of useful work allows to determine real reserves to increase efficiency of locomotives' operation, the main of which is associated with the organization of transportation process. The second place belongs to reduction of downtime when waiting for TMR, and the third place belongs to TMR, consisting mainly of current repair-1 and unscheduled repair.

3. Low probability of correspondence of statistical data to normal distribution law of a random variable proves multimodality of data, and as a result their low reliability. It is necessary to cluster data to obtain unimodality, after receipt of which further detailing is not required. For efficient use of information on operations in the research, it is necessary to cluster it in terms of traction type, locomotive series, regions of operation, types of traffic, between-repairs runs, and other influencing factors.

4. Reduction of downtime at TMR is possible not only through increase in quality of repair processes, but also through increase in quality of locomotives' operation itself. There are mass cases of violations of operating modes (VOM), which significantly reduce reliability of locomotives: more than one third of all failures take place because of VOM. Implementation of algorithmic protection measures will significantly increase reliability of locomotives and efficiency of their operation.

5. While at this stage the research has not followed the objective to test the suggested methods to evaluate efficiency of locomotives' operation at railways other than network of JSC Russian Railways, nor in other countries, the methods seem to be rather universal to be used for different railways, once they are adapted to parameters of initial data, their range and target values.

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