Formation of new principles and models of operation of structural units of the industry under the conditions of implementation of digital technologies

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Abstract. The construction of a high-tech modern model “Digital Railroad” is currently a key element, the implementation of which is planned for the near future. The project will create new principles and models for the work of all structural divisions of the industry in the context of the widespread penetration of digital technologies. The emergence of digital technologies will make it possible to transfer the organization and technology of functioning of transport and other systems to a qualitatively new level, new information technologies will make it possible to optimize the operation of rolling stock. According to the results of the analysis of the performance indicators of the service locomotive depot Irkutskoye, according to the model of “full service” of the locomotive fleet, it was revealed that the indicators negatively affect the financial results of the depot and negatively affect the quality of the repair performed in general. To solve this problem, it is proposed to use an automated locomotive fleet reliability management system in the Irkutsk service locomotive depot, the implementation of which will increase the availability factor, reduce downtime in repair depots, and minimize resource consumption for all types of repair and maintenance. The main consumer of the services of the locomotive fleet reliability management system is, first of all, the Russian Railways holding company and the traction directorate. They are interested in the reliable operation of the rolling stock, since during the operation of locomotives there are risks: comments on the operation of the locomotive fleet, failures and malfunctions of various degrees of complexity, cases violations of train traffic safety.

1. Introduction

According to the current system of reforming the holding, JSC Russian Railways (hereinafter referred to as JSC Russian Railways), repair and maintenance of the locomotive fleet of the industry are carried out in full by service locomotive depots, which were created on the basis of previously existing repair locomotive depots. At the same time, they are not included in the system of Russian Railways, but are included in the structure of TMH-Service LLC (Transmashholding), established in June 2010 according to the concept of “Development of a service system and creation of a single center of responsibility for the technical condition of locomotives”, approved by Russian Railways [1-4]. Despite the reforms, the
holding continues to be the owner of these repair depots, locomotive fleet maintenance points (PTOL), as well as the repair equipment and other fixed assets available in structural divisions [5-7].

The system of work is in accordance with the established model of “full service” for the locomotive fleet belonging to JSC Russian Railways, which provides for a procedure for full responsibility for the technical condition of the mobile units by the service company during their full-service life. At the same time, the service company produces both direct maintenances, planned and unscheduled types of repair (HP), and also carries out high-quality training of personnel, investing in the technological equipment of repair enterprises [4, 8].

2. Evaluation of the efficiency of the "full service" model of the locomotive fleet owned by Russian Railways by the example of the service locomotive depot Irkutskoye

Taking into account the established operating technology, service depots should focus on performing high quality repairs of the locomotive fleet, subject to minimizing financial and time costs, which should ensure high-quality performance of the assigned types of work.

The service locomotive depot Irkutskoye, in accordance with the established work technology, performs the following types of work: repair and maintenance of electric locomotives for passenger traffic EP1, EP1P, freight electric locomotives for pushing traffic 3ES5K (Ermak) in the volume of TR-1 and TR-2 and shunting locomotives in the volume of TO-3 and TR -1. The depot includes a PTOL of network significance, located at station Irkutsk-Sortirovchny and PTOL at station Slyudyanka [5, 9-10].

To assess the labor intensity of the production of certain types of repairs and series of locomotives in the given repair units, special regulatory coefficients are used, which are separately set for each series of a mobile unit. Table 1 shows the given locomotive repair program in the given units.

| Table 1. Indicators of the repair program of the service locomotive depot Irkutskoye. |
|---------------------------------|--------|--------|--------|--------|--------|--------|
| 2016 fact | 2017 fact | Change by 2016, % | Plan 2018 | Fact 2018 | Implementation of a plan, % | Change, % by 2016 by 2017 |
| 1621.70 | 1580.57 | 97.46 | 1523.78 | 1539.66 | 101.04 | 94.94 | 97.41 |

The main reasons for the reduction in the repair program of the service locomotive depot Irkutskoye are reduction in the repair program for electric locomotives; uneven loading of stalls of repair shops due to stopping locomotives for a complaint, unscheduled repairs, waiting for work. They also include untimely statement for repair due to excess downtime for repairs owing to a large number of additional work; lack of timely provision of the depot by OOO TMH-Service with the necessary spare parts and equipment [2, 11-13].

For a more detailed description of the work and in order to develop measures to optimize the activity of the service locomotive depot Irkutskoye, it is necessary to analyze the quality indicators. They include the coefficient of technical readiness of locomotives (CTR), idle time of locomotives for scheduled and unplanned types of repair, the volume of failures of the used technical means, the number of calls of mobile units for unscheduled types of repairs, the number of events related to the violation of train traffic safety and the occurrence of risk cases.

CTR of locomotives directly depends on the level and quality of maintenance and repair of this rolling stock. Timely detection and elimination of recorded faults, compliance with the rules of technical operation contribute to an increase in CTR.

According to the values presented in Figure 1, it can be seen that the KTG both for electric locomotives and for diesel locomotives has a tendency to decrease, while it should be noted that the value of the indicator depends on other qualitative indicators of the enterprise, the dynamics of which is presented in Table 2.
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Figure 1. The coefficient of technical readiness of locomotives.

Table 2. Quality indicators of the service locomotive depot Irkutskoye.

| Index                        | 2016 fact | 2017 fact | Change by 2016, % | 2018 Fact | Change, % by 2016 | Change, % by 2017 |
|------------------------------|-----------|-----------|-------------------|-----------|-------------------|-------------------|
| Electric locomotives         |           |           |                   |           |                   |                   |
| Downtime for scheduled repairs | Norm      | 72.00     | 72.00             | 100.00    | 72.00             | 100.00            |
|                              | Maintenance-2, hour | 114.09 | 96.00 | 84.14 | 112.80 | 98.87 | 117.50 |
|                              | Maintenance-1, hour | 31.00 | 31.83 | 102.68 | 31.00 | 100.00 | 97.39 |
| Unscheduled repairs          | Cases     | 352.00    | 371.00            | 105.40    | 403.00            | 114.49            |
|                              | Downtime, hour | 18685.23 | 19654.85 | 105.19 | 21506.01 | 115.10 | 109.42 |
| Diesel locomotives           |           |           |                   |           |                   |                   |
| Downtime for scheduled repairs | Norm      | 45.15     | 38.00             | 84.16     | 38.00             | 84.16             |
|                              | Maintenance-1, hour | 143.12 | 130.60 | 91.25 | 117.20 | 81.89 | 89.74 |
|                              | Services-3, hour | 27.00 | 27.00 | 100.00 | 27.00 | 100.00 | 100.00 |
| Unscheduled repairs          | Cases     | 69.00     | 50.00             | 72.46     | 66.00             | 95.65             |
|                              | Downtime, hour | 10705.21 | 9013.65 | 84.20 | 10401.25 | 97.16 | 115.9 |

The idle time of electric locomotives for all types of scheduled repairs exceeds the established standard. So, on Maintenance-2, the average downtime for 2018 is 112.8 hours, with the established rate not exceeding 72 hours, on Maintenance-1, the downtime is 76.8 hours with the established rate of 31 hours and on Services-2u - 109.7 hours when set to 30 hours. Such dynamics have such reasons as: exceeding the idle rates of electric locomotives for repairs associated with waiting for a free stall for repairs, lack of spare parts, untimely delivery of electric locomotives for scheduled repairs (out of schedule), absence or employment of repair personnel, performance of overcycle work, etc.
The downtime of diesel locomotives on planned types of repairs has an uneven trend: a decrease is observed in the repair cycle Maintenance-1, and an increase in indicators is noted in the Services-3 cycle. The average idle time of diesel locomotives for repair in the Maintenance-1 cycle in 2018 amounted to 117.2 hours, which is 25.92 hours less than it was in 2016, or 18.11%. According to the Services-3 cycle, in 2018 compared to 2016, there is an increase in the idle time of diesel locomotives by 7.84 hours, or by 13.39%. The idle rates of diesel locomotives for repairs, as well as for electric locomotives, are not met, the idle times for planned types of repairs exceed the standard indicator at least twice.

The main reasons for exceeding the standards of idle time for diesel locomotives in repair are similar to those associated with electric locomotives, but there are a number of other reasons. Thus, failure to comply with the idle time standards for diesel locomotives during scheduled repairs of Maintenance -1 is associated with additional repairs due to violation of operating modes, including interference in the proper operation of locomotive systems and additional work. The list of additional work to be carried out contains oil change, wheelset turning, elimination of water leakage through the cylinder covers of a diesel engine, elimination of oil leakage through the connection of valve boxes with cylinder covers, etc. The main reason for the increase in the downtime of diesel locomotives at scheduled Services -3 is additional work. These are replacement and repair of the air cooler, revision of the compressor with removal from the locomotive, replacement and repair of the water pump, elimination of oil and water leaks through the cylinder covers of the diesel engine. These also include repair of the traction motors, cooling fan, repair of the clutch compressor, repair of the synchronous single-phase exciter drive (replacement of bearings), etc. [7, 14].

In case of failure of units and assemblies of mobile units, they are sent for unscheduled repair (UR), which leads to the need to divert the workforce from the planned work, requires additional costs of labor resources, spare parts, materials. These financial costs are non-productive, lead to an increase in the cost of current types of repairs and maintenance, since the costs of unscheduled repairs of mobile units are related to the type of repair and maintenance that led to the failure.

The increase in the number of cases of UR of electric locomotives in 2018 compared to 2016 is 51 cases, and compared to 2017, 32 cases, or an increase occurred by 14.49% and 8.63%, respectively. In 2018, the number of UR diesel locomotives was 66 cases, which is 32% more than in the previous year. An increase in the volume of calls of electric locomotives to UR occurs due to the failure of traction motors, wheelsets with axle boxes, non-observance of the mode of driving freight trains, excess of weight standards and poor-quality repairs.

The greatest downtime at UR was 551 hours of the EP1P # 023 electric locomotive due to the presence of current surges in operation. There are 221 hours of electric locomotive EP1P # 057 due to the presence of current surges due to failure of the UVO2P cassettes. 451.38 hours of electric locomotive EP1P # 021 due to the restoration of the electric locomotive after the alarm and fire extinguishing system have been triggered. 179.74 hours of the electric locomotive 1.5VL80tk No. 1014/2016 are due to the failure of the traction transformer. The overestimated downtime is due to a long decision on the part of DT to organize work to put the electric locomotive into operation with its subsequent transfer to the balance of the Krasnoyarsk railway.

During operation, there are failures in the operation of individual units of the locomotive, which are caused by wear and tear, design flaws of mobile units, unsatisfactory quality of repair and maintenance, violation of operation technology, which is presented in Table 3.

In 2018, 88 cases of failures were recorded in the service locomotive depot Irkutskoye, which is 3.53% higher than this indicator for the same period in 2017. In 2017, compared to 2016, there was a decrease of 2.3%. For the entire analyzed period, the largest number of failures was recorded for electrical equipment, 45 cases in 2016, which is 51.72% of the total number of failures, and during the period under review, failures for electrical equipment are increasing.

According to the analysis of the causes of malfunction in the electrical equipment of mobile units, the following were revealed: short circuit in the wire circuits, malfunctions of the main controller and control circuits, damage to the insulation of electrical equipment, breakage of the current collector. So,
in 2018, five cases of failures were recorded for auto brake equipment. Faults: breakage of the connecting sleeve of the end valve of the feed line, malfunction of the driver's valve, breakage of the brake line pipe elbow. On safety devices 8 cases. Fault: short circuit of the armature winding, interturn short circuit of the traction motor poles.

**Table 3. Distribution of equipment failures at the service locomotive depot Irkutskoye.**

| Equipment type         | 2016 fact | 2017 fact | Change by 2016, % | 2018 Fact | Change, % by 2016 by 2017 |
|------------------------|-----------|-----------|-------------------|-----------|--------------------------|
| Electrical equipment   | 45        | 48        | 106.67            | 51        | 113.33 106.25            |
| Auto brake equipment   | 8         | 6         | 75.00             | 5         | 62.50 83.33              |
| Safety devices         | 12        | 5         | 41.67             | 8         | 66.67 160.00             |
| Mechanical equipment   | 4         | 6         | 150.00            | 7         | 175.00 116.67            |
| Electronic equipment   | 5         | 8         | 160.00            | 4         | 80.00 50.00              |
| Traction motor         | 4         | 5         | 125.00            | 3         | 75.00 60.00              |
| Auxiliary machines     | 2         | 1         | 50.00             | 3         | 150.00 300.00            |
| Locomotive equipment   | 2         | 2         | 100.00            | 4         | 200.00 200.00            |
| Other                  | 5         | 4         | 80.00             | 3         | 60.00 75.00              |
| Total                  | 87        | 85        | 97.70             | 88        | 101.15 103.53            |

Further, it seems appropriate to analyze the distribution of failures for organizational reasons, table 4.

**Table 4. Distribution of failures due to organizational reasons of the service locomotive depot Irkutskoye.**

| Reasons for malfunction | 2016 fact | 2017 fact | Change by 2016, % | 2018 Fact | Change, % by 2016 by 2016 |
|-------------------------|-----------|-----------|-------------------|-----------|--------------------------|
| Total rejections        | 87        | 85        | 97.70             | 88        | 101.15 103.53            |
| Through the fault of the Service Locomotive Depot, including: | | | | | |
| - locomotive maintenance point | 43 | 38 | 88.37 | 41 | 95.35 107.89 |
| - Electrical machine shop | 1 | 2 | 200.00 | 4 | 400.00 200.00 |
| - Electrical apparatus shop | 1 | 0 | 0.00 | 2 | 200.00 - |
| - Electronics | 0 | 2 | - | 1 | - 50.00 |
| - Hitchhiking shop | 5 | 3 | 60.00 | 5 | 100.00 166.67 |
| - Maintenance workshop | 9 | 9 | 100.00 | 16 | 177.78 177.78 |
| - Automatic shop | 6 | 4 | 66.67 | 5 | 83.33 125.00 |
| - Hardware workshop | 0 | 2 | - | 1 | - 50.00 |
| Wines of repair of other Service locomotive depots and traction part repair | 11 | 17 | 154.55 | 15 | 136.36 88.24 |
| Wines of the locomotive brigade Traction part operational | 12 | 5 | 41.67 | 2 | 16.67 40.00 |
| Wines Traction part operational-5 | 0 | 1 | - | 0 | - 0.00 |
| Factory wines | 0 | 1 | - | 0 | - 0.00 |
| Constructive flaw | 1 | 2 | 200.00 | 3 | 300.00 150.00 |
| Degradation wear | 2 | 8 | 400.00 | 6 | 300.00 75.00 |
| Track part | 0 | 1 | - | 0 | - 0.00 |
| Power supply distance | 0 | 3 | - | 1 | - 33.33 |
| Center manager | 3 | 1 | 33.33 | 1 | 33.33 100.00 |
| other | 15 | 8 | 53.33 | 19 | 126.67 237.50 |
Of the total number of marriages in 2018 in the number of 88 cases, the distribution according to the perpetrators occurred: due to the fault of the Service Locomotive Depots, 41 cases were recorded (unsatisfactory quality of maintenance and repairs), including 16 cases due to the fault of the maintenance shop. The reasons for the marriage were the violation of the requirements of the instructions for maintenance and repair of electric locomotives of alternating current, poor-quality repair of electric locomotives, lack of control by the master of the complex team over the quality of repair of electrical equipment.

The analysis of the qualitative indicators of the service depot Irkutskoye shows the level of service at the depot, characterizes production activities and their effectiveness. It should be noted that, in addition to analyzing qualitative indicators, it also seems appropriate to analyze costs and their dynamics. It is necessary to consider the costs both for the main types of repairs (maintenance and repair), and for unscheduled repairs, which is necessary in order to determine in which areas the greatest expenditure of funds is going. In general, the cost analysis should show whether the operation of the service locomotive depot is effective from a financial point of view, Table 5.

Table 5. Distribution of expenses for planned and unplanned types of repairs.

| Costs                          | 2016 fact | 2017 fact | Change by 2016, % | 2018 Fact | Change, % by 2016 by 2017 |
|-------------------------------|-----------|-----------|------------------|-----------|---------------------------|
| Total for scheduled maintenance and repair of locomotives, million rubles: |           |           |                  |           |                           |
| 1. For scheduled maintenance and repair of electric locomotives, million rubles: |           |           |                  |           |                           |
| - Maintenance-1               | 64.307    | 63.154    | 98.207           | 59.582    | 92.652                   |
| - Maintenance-2               | 5.858     | 5.586     | 95.357           | 5.586     | 95.357                   |
| - Services-2u                 | 10.514    | 10.131    | 96.357           | 8.173     | 77.734                   |
| 2. For scheduled maintenance and repair of diesel locomotives, million rubles: |           |           |                  |           |                           |
| - Maintenance-1               | 2.265     | 2.181     | 96.291           | 1.846     | 81.501                   |
| - Services-3                  | 9.714     | 9.536     | 98.168           | 9.332     | 96.068                   |
| For unscheduled maintenance and repair of locomotives, million rubles: |           |           |                  |           |                           |
| Total, million rubles         | 16.572    | 16.587    | 100.091          | 18.324    | 110.572                  |

In general, the costs of all types of repairs have a steady downward trend. Expenses for scheduled types of repairs of electric locomotives are steadily decreasing, this decrease for two years amounted to 7.338 million rubles or 9.1%, for diesel locomotives there is also a decrease in costs, which amounted to 0.801 million rubles or 6.69%. The reasons for the cost savings lie not in optimizing material cost management or improving the repair process, but in reducing the locomotive repair program. While the number of unscheduled repairs is increasing both for diesel locomotives and electric locomotives, which in turn leads to an increase in the cost of unscheduled repairs. So in 2018, the costs associated with the implementation of unscheduled repairs amounted to 18.324 million rubles, which is 1.752 million rubles more than in 2016 or 10.57%.

Thus, despite the stable decrease in repair costs, the quality indicators have a negative trend: the number of failures is growing, the number of unscheduled repairs is increasing, the standards of locomotive downtime for repairs are not observed, and the CTR of locomotives decreases [1, 15-17].
Based on the results of the analysis of the qualitative indicators of the operation of the service locomotive depot Irkutskoye according to the “full service” model of the locomotive fleet owned by Russian Railways, it should be noted that the deterioration of these indicators negatively affects the financial results of the depot and the quality of the repairs performed in general. Thus, quality indicators, being the key factors in increasing the efficiency of the depot, should be minimized. So, ideally, the number of equipment failures and the number of unscheduled repairs (UR) should tend to zero, while the downtime should also decrease on planned and unplanned types of repair. At the same time, the downtime for scheduled repairs should not exceed the established standard values.

3. Automated locomotive fleet reliability management system

To solve this problem, it is proposed to use the automated locomotive fleet reliability management system (ASCTR) in the service locomotive depot Irkutsk.

ASCTR is aimed at the following key performance indicators of the enterprise:

- increase in the availability of locomotives;
- reduction of downtime of locomotives in repair depots;
- reduction of resource consumption for maintenance and repair of locomotives.

The rest of the ASCTR performance indicators are of a secondary nature.

During the operation of locomotives, failures occur in the operation of individual units of the locomotive. Failures are caused by wear, structural deficiencies of the RTS, unsatisfactory quality of repair and maintenance, etc. In order to identify pre-failure conditions, eliminate emerging failures as soon as possible and generally increase the reliability of locomotives, it seems appropriate to use ASCTR.

ASCTR is a set of technological, technical, mathematical, labor and other types of resources, which are combined into an integral system in order to increase the level of reliability of using the locomotive fleet, reduce the downtime of locomotives for repairs, and reduce the cost of maintenance and repair. The main attention is paid to the technology for carrying out such types of repairs as maintenance and repair of locomotives, the structure of enterprise management, the implementation of the principle of control and optimization of performance indicators.

ASCTR consists of three main blocks: software, technological and resource support. The construction of a high-tech modern model "Digital Railway" at JSC "Russian Railways" is currently a key element in ensuring the digital economy of the Russian Federation, the implementation of which is planned for the near future. The project will create new principles and models for the work of all structural divisions of the industry in the context of the widespread penetration of digital technologies. The emergence of digital technologies will make it possible to transfer the organization and technology of functioning of transport and other systems to a qualitatively new level. New information technologies will allow one to optimize the operation of rolling stock and infrastructure: high-speed data transmission networks, big data processing technologies, intelligent systems, mobile applications, the Internet of Things [3, 18]. In connection with this strategy, we will pay most attention to the consideration of the ASCTR software block, which includes a unified system for monitoring the technical condition of locomotives (USMT), data decoding systems for on-board microprocessor systems of a locomotive (MSUT), an automated system for technical diagnostics (ASTD), information systems of railway transport (ASCRT).

USMT is essentially an automated process control system (APCS), which should combine in a single information space all the data on the reliability of locomotives, thereby creating the prerequisites for integrated management of locomotive reliability. USMT is used to identify incidents (failures, pre-failure states, violations of operating modes, remarks of drivers, station attendants and dispatchers, other situations other than normal) entering the locomotive system using remote control of data transmission from various sources - MSUT, ASTD, ASCRT. Of all the listed information systems, information about possible incidents in the form of diagnostic messages is transmitted to the USMT, where an incident registration sheet is automatically created. The next step is incident lifecycle management, problem management and service level management.
In the process of locomotive control, MSUT interrogates sensors, collects and accumulates diagnostic data. The MSUT data are read and analyzed at specialized workplaces (AWS MSU), where the incident is found using special algorithms and the decryption data are attached to confirm the malfunction. Information from the MSU AWS is sent to the USMT in a unified format: date and time of the incident, series, number, locomotive postscript, incident code, brief description, place and circumstances of the incident.

The use of diagnostic data from the MSUT significantly increases the amount of diagnostic information and, as a consequence, a more complete understanding of the technical condition of the locomotive, it becomes possible to fix the pre-failure state in real operating conditions, hence it becomes possible to control the operating modes of locomotives. The operating experience of modern traction rolling stock testifies to the growing role of built-in and on-board diagnostic systems [6].

Another diagnostic tool for locomotives is ASTD - portable or stationary diagnostic systems, as a rule, are located in the depots themselves and at the locomotive maintenance points and are designed to monitor and predict the technical condition of the locomotive and its individual components and assemblies. Information from ASTD is also sent to the USMT in a unified format.

All initial information is recorded in various information systems of the ASCRT - integrated automated accounting system, monitoring the elimination of failures of technical means (KASANT), integrated automated subsystem for accounting and analysis of technological failures (KASAT).

Management of these risks is carried out on the basis of three sources of information: AWS MSU, ASTD and ASCRT. In the process of constantly receiving information, a database is formed, which is the basis of a single information space for ASCNT. Based on the above, it seems important to consider the structure of the functioning of the system, which is shown in Figure 2.

![Structure of information flows of ASCTR](image)

Figure 2. Structure of information flows of ASCTR.

The proposed ASCTR makes it possible to consider pre-failure states, identify failures, as well as violations of operating modes, identify trends in parameter changes, the intensity of failures, use previous statistical data on the rate of development of a pre-failure state into failure. In addition to these parameters, the data of the entire life cycle of the incident are analyzed: the time of setting up for repair, the time of repair, the time to search for a spare part, etc., the quality of the repair performed, the number of participants in the elimination of the incident, the consumption of other types of resources.
4. Conclusion
The introduction of the proposed ASCTR will allow you to get an effect due to:

- reducing the volume of malfunctions of the equipment of the locomotive fleet by eliminating or minimizing the number of violations of their operating modes;
- minimization of failures of the fleet of locomotives on the line by identifying pre-failure conditions and taking preventive measures;
- reducing the downtime of locomotives in the depot for repair and maintenance operations by reducing the number of failures and timely planning the supply of required spare parts of appropriate quality;
- reducing the cost of maintenance and repair due to the elimination of high-cost failures (due to their prevention);
- optimal use of the cash resources of the service depot aimed at innovative development through factor analysis and identification of the weakest points in production.

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