Approaches to Improving the Locomotive Maintenance Organization System Through the Introduction of Reliability Centered Maintenance

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Abstract. The efficiency of the locomotives depends on the rational use of technical resources intended for the smooth operation of railway transport. The organization of maintenance of locomotives is one of the most important areas in the railway sector and is constantly under development and improvement. One of the directions for improving the locomotive maintenance system is the use of the RCM methodology – Reliability Centered Maintenance – to optimize the planning of processes related to the maintenance of locomotives. In order to improve the maintenance system of locomotives, the authors made calculations concerning the predicted wear of wheelsets in locomotives based on a critical analysis of data obtained from the locomotive depot. The resulting calculations make it possible to predict the setting of locomotives for maintenance, considering the previous analytical data obtained during maintenance. The aim of improving locomotive maintenance is the reduction in downtime for locomotives that are idle waiting for maintenance. The paper presents the statement of the problem with the use of input data, analysis of the data, and their application for further prediction of equipment wear. The research shows that the application of the RCM methodology on the example of a locomotive depot allows for obtaining predictive data for subsequent use in the management of the maintenance system.

Keywords: Railway · Rolling stock · Locomotives · Reliability Centered Maintenance (RCM) · Maintenance organization

1 Introduction

Improving the organization of maintenance for railway rolling stock is an urgent issue for the railway industry of Ukraine, which is determined by the increase in the number of failures in the operation of rolling stock. As a result, there is an increase in the cost of maintenance and repair of wagons and locomotives, a decrease in profitability due to unscheduled repairs and lengthy downtime of rolling stock on maintenance [1].

When managing the technical condition of locomotives, the following types of maintenance systems are used: maintenance system to failure (reactive maintenance), routine-preventive maintenance system (periodic maintenance), maintenance system by condition (predictive maintenance), the system of integrated management of the technical

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condition (prescriptive maintenance) [2]. Given the complexity of the locomotive as a technical object, as well as the technical possibilities of introducing diagnostic systems on locomotives, in most cases a combination of the systems listed above is used. A detailed analysis of the feasibility of using one or another locomotive maintenance system is described in [3–5]. In [3], the authors considered the features of choosing a maintenance system for locomotives equipped with on-board diagnostic systems. The paper [4] is devoted to a comparative analysis of the use of various approaches in the organization of the locomotive maintenance system of Ukrainian Railways. Relationships of the stages in the transition from a routine-preventive system to a maintenance system for locomotives according to technical conditions, as well as a comparative analysis of locomotive maintenance strategies, are given in the paper [5].

Most of the techniques for choosing the parameters of the maintenance system are based on the use of statistical data on the reliability of locomotives in operation and are focused on optimization criteria. Optimization criteria, as a rule, are the adjustment of overhaul periods and repair volumes, taking into account operating conditions, repair organization, reliability level, minimizing the maintenance costs, minimizing the number of unscheduled repairs, and minimizing the life cycle costs. In addition to using the optimization approach, methodologies of RCM (Reliability Centered Maintenance), RBM (Risk Based Maintenance), and RAMS (Reliability, Availability, Maintainability and Safety) have become widespread recently [3].

Currently, when building maintenance systems for technical facilities, the risk-based maintenance methodology (RBM) for traction rolling stock is widely used. The RBM combines both optimization approaches to building maintenance systems and elements of RCM using preventive maintenance approaches.

The basic concept of RBM is the concept of "risk" and its minimization or support at a given level. The concept of "risk" is widely used in the economic and technical spheres. The usage examples of RBM approaches in railway transport are given in [6–8]. The complexity of using RBM is the need to collect and analyze large amounts of statistical data. Moreover, the RBM approach is more appropriate to use when managing a rolling stock fleet, since the construction of an individual maintenance system is complicated by the duration of data collection.

One of the directions for improving the rolling stock maintenance system is the use of the RCM methodology to ensure the continuous functioning of railway enterprises and transport companies. The RCM is maintenance aimed at ensuring the reliability of equipment. It is a methodology that enables an enterprise to optimize an asset maintenance and repair program [9–11].

RCM is a systematic approach to maintaining, analysing, and accounting for possible failures of all systems of a research object or an entire company. The major priority is given to safety and efficiency from the viewpoint of the profitability of the asset being serviced, which makes it possible to identify and classify effective and possible for applying tasks in the preventive maintenance for the fleet [9, 12]. Therefore, RCM is about reducing maintenance costs, focusing on critical system functions, and excluding maintenance activities that are not strictly necessary. The methodological foundations of approaches in various fields of technology are considered in [9, 12, 13]. Examples of using the RCM methodology in the development of rolling stock maintenance systems are given in [14–16].

The main objective of the RCM methodology is to extend the life of the equipment and reduce downtime in the most efficient way. The aim of this methodology is to identify and prevent known or predictable types of functional failures of equipment, system, or other technical facility. When applying this methodology in the maintenance of rolling stock, a systematic approach to maintenance, analysis, and accounting of possible failures of all rolling stock systems is noted [14]. Top priority is given to safety and economy in terms of the cost-effectiveness of the serviced nodes, which allows you to identify and classify effective and possible applying tasks in the preventive maintenance for the fleet of locomotives.

The RCM methodology is used to build a maintenance system focused on ensuring the operability of the locomotive, in this case, the requirement for a fully serviceable condition of the locomotive is not always ensured. This approach is relevant in the context of the need to reduce the cost of maintenance performance and repair of locomotives. At the same time, a key factor in the RCM methodology is the performance of engineering analysis for the functions of locomotive nodes and systems in order to define how each type of failure can be detected and prevented, as well as the consequences of a failure occurrence. One of the main tools in the RCM methodology is a system for monitoring operational parameters, which for locomotives is implemented through a maintenance system, the use of monitoring, and diagnostic systems in operation.

From the viewpoint of approaches to the management of the technical condition of the locomotive, the RCM methodology is focused on implementing a combination of approaches: reactive, periodic, and predictive maintenance. For each major node or system of the locomotive, the most appropriate approach is selected. When choosing an approach, the criticality of the failure, the rate of failure development, the nature of the development of degradation processes, and the engineered capability in monitoring and diagnosing operational parameters are taken into consideration. This ensures high efficiency in monitoring the technical condition of the locomotive with a reduction in maintenance costs.

The aim of the approaches in the RCM methodology is to concentrate efforts on maintaining the locomotive in working condition, reducing the consequences of failures, and introducing individual planning of the frequency and scope of maintenance and repair work for each specific locomotive.

The Reliability Centered Maintenance methodology makes it possible to implement an individual maintenance system for rolling stock, requires the collection of a large amount of data for each individual rolling stock unit, and also requires the fastest possible processing and analysis. When considering the implementation of the Reliability Centered Maintenance methodology, one can choose groups of equipment or individual technical nodes of the rolling stock.

The results of solving the problem of building an individual locomotive maintenance system using RCM approaches are further used both when planning setting for locomotive maintenance and for planning the load level of locomotive repair shops, and the volume of required resources. An example of building a load model for a locomotive repair shop using data on the reliability of locomotive nodes and resources required for repair work is given in [17].

2 Research Methods Used for the Investigation

In this paper, as an example of the use of RCM approaches, the authors conducted research concerning the possibility of defining an individual remaining resource for locomotive nodes and further planning work related to the maintenance of locomotives.

As a node for the research, the wheelsets of the locomotive were chosen. The choice of wheelsets is explained by the simplicity of obtaining statistical data on wear, as it does not require sophisticated measuring equipment; on the other hand, the wheelset is an important part, the condition of which directly affects traffic safety. During the research, we collected statistical data on the wear of wheelsets of eight-axle passenger electric locomotives ChS7 in one of the locomotive depots of the Ukrainian Railways.

The purpose of the research was to analyze the wear values of the wheelsets of electric locomotives, on the basis of the analysis, calculate the expected moment of the next maintenance for wheelset turning, and also make a predictable calculation of the ultimate wearing of the wheelsets rim. The data obtained from the locomotive depot allowed us to analyze and define the predicted residual life for each wheelset and for the locomotive as a whole.

According to the technical documentation [18], the limiting parameters for the use of a wheelset on an electric locomotive are the boundary values of the rim thickness and the flange of the wheelsets. For the investigated electric locomotives, the boundary values of the rim thickness range from 95 mm (h_{max}) and 45 mm (h_{min}). The boundary values of the flange thickness t fact of the wheelset are 30 mm – t_{max} and 25 mm – t_{min}, respectively.

Based on the analysis of the process in the operation of electric locomotives, it was found that in 95% of cases, the setting of the locomotive for wheelsets turning occurs due to a decrease in the thickness of the wheelset flange to a critical value $t_{min} = 25$ mm. This happens for a number of technical reasons, which include the natural wear of V_{wn} (metal-on-metal friction), the mode and areas of operation of the locomotive, and the quality of the metal from which the locomotive rims are made is of great importance. The t_{min} parameter limits the locomotive's being in operation. W_{ith} a value of $t_{min} <$ 25 mm, the operation of the locomotive is prohibited. In order to restore the allowable value of the flange thickness t fact to allowable values within $t_{min} - t_{max}$, maintenance of the locomotive is carried out for wheelsets turning. While performing maintenance on wheelsets turning in order to eliminate the rejection parameter for the wheelset flange thickness t fact in the process of wheelsets turning, along with a change in the flange thickness t fact, the value of the rims thickness of the wheelset h fact also changes. From the above, it follows that during the maintenance of wheelsets turning, due to the critical value of the locomotive flange parameters, both the value of the locomotive flange parameter and the value of the wheelset rims thickness change.

The main task of the research is to analyze the statistical data collected at the depot and perform a predictive calculation concerning the setting of a locomotive for maintenance on wheelsets turning, as well as perform a predictive calculation of the residual period in the operation of the locomotive wheelsets, which (a period) depends on the thickness of the wheelset rim.

Definition of the predicted residual period (mileage) in the operation P_{expl} of the wheelset until the next maintenance for wheelset turning is defined:

$$P_{expl} = \frac{t_{res} \cdot 10^4}{V_g}, \quad (1)$$

where t_{res} – the residual thickness of the wheelset flange, mm; V_g – the rate of natural wear of the wheelset flange thickness, mm/km.

The Eq. (2) is used to define the residual thickness h_{res} of the wheelset rim:

$$h_{res} = h_{fact} - h_{min}, \quad (2)$$

where h_{res} – the residual value of the wheelset rim thickness, mm; h_{fact} – the actual value of the wheelset rim thickness, mm; h_{min} – the minimum value of the wheelset rim thickness, mm.

To define the natural wear rate V_{wn} of the wheelset rim thickness, equation can be used:

$$V_{wn} = \frac{h_{fact1} - h_{fact2}}{d_1 - d_2} \cdot 10^4, \quad (3)$$

where V_{wn} – the rate of natural wear of the wheelset rim thickness, mm; h_{fact1} – the actual value of the wheelset rim thickness at the mileage of d_1; h_{fact2} – the actual value of the wheelset thickness at the mileage of d_2; d_1 – the value of the locomotive (wheelset) mileage when measuring the value of the wheelset parameters h_{fact1}; d_2 – the value of the locomotive (wheelset) mileage when measuring the value of the wheelset parameters h_{fact2}.

The turning factor has a significant impact on the wear rate of the rim thickness. To define the predicted residual period of operation P_{expl} for the wheelset, we use equation:

$$P_{expl} = \frac{h_{res} \cdot 10^4}{V_{wn} + V_m}, \quad (4)$$

where h_{res} – the residual value of the wheelset rim thickness, mm; V_{wn} – the rate of natural wear of the wheelset rim thickness, mm/km; V_m – the wear rate of the wheelset rim thickness, taking into account turning, mm/km.

Setting a locomotive (on the example of an eight-axle locomotive) for maintenance on wheelset turning is carried out from the condition of choosing the minimum residual mileage for all wheelsets in the locomotive:

$$P_{expl}^{locom} = \min\{P_{expl}^1, P_{expl}^2, P_{expl}^3, P_{expl}^4, P_{expl}^5, P_{expl}^6, P_{expl}^7, P_{expl}^8\}. \quad (5)$$

Thus, in order to implement individual prediction of the residual life for locomotive wheelsets using the approaches of the RCM methodology, it is necessary to organize a system for collecting operational indicators, such as the fringe thickness and the rim thickness. Having a sufficient amount of statistical data, it is possible to predict the mileage of the locomotive at which it is necessary to perform the wheelset turning, as well as the resource remaining for the wheelset change. Let us consider a practical example of using this approach.

3 Results

To conduct research on predicting the wear of wheelsets in locomotives, four main-line electric passenger locomotives of the ChS7 series were chosen as research objects. All selected electric locomotives were operated in the same conditions: the same railway line, similar trains combinations, all locomotives from one locomotive depot. When performing the research, the results of monitoring the parameters of wheelsets in electric locomotives from the moment in the overhaul of electric locomotives were collected. When performing overhauls, new wheelsets are installed. At the time of data collection, the mileage of electric locomotives after overhauls ranged from 250 thousand km to 400 thousand km. The average mileage of a wheelset after a major overhaul before the change is 400–500 thousand km. For the operation area under examination. For two electric locomotives, statistics were collected on the operating interval of 350 and 400 thousand km of mileage. For the other two, it was in the range of up to 250 thousand km of mileage. Thus, it became possible to further predict the wear of the wheelset rim in the electric locomotives, and compare the predicted resource with the actual wear data of the wheelsets under similar operating conditions.

For clarity in displaying the results of the analysis, the paper presents data on the analysis of the wear for the first wheelset in each electric locomotive. As noted earlier, one of the most important parameters that limit the setting of the locomotive for maintenance for wheelset turning is the wheelset flange thickness. In this regard, an analysis was made of the wear rate of the wheelset flange. When performing the analysis, the rate of change in the wheelset flange thickness per unit of the mileage was defined. An example of a graph showing the wear rate of the wheelset flange is shown in Fig. 1. As can be seen from the graph, there is uneven wear of the flange during the operation of electric locomotives. Similar uneven wear of the flange was observed in all electric locomotives. Predicting the residual thickness of the flange without an analysis of additional conditions that characterize the operating conditions is not advisable because of the low predictive accuracy. The reasons for uneven wear can be seasonal factors, the condition of the railway track, etc.

The parameter on which the service life of the wheelset depends is the rim thickness. During the operation of the locomotive, this parameter varies from 90 mm to 45 mm. The reasons for the rim thickness reduction are two factors: natural wear and the performance of maintenance for wheelset turning due to wear of the wheelset flange (artificial wear). Based on the analysis of statistics, graphs of wear for the wheelset rim in the electric locomotive are constructed. As one can see from the graph, the main reason for changing the rim thickness is the rim returning. The steps on the wear graph correspond to the moments when there is a wheelset turning. Similar to the flange wear, the rim wear, the frequency of turning, and the reduction in the rim thickness at wheelset turning are not uneven. Thus, the long-term planning in the remaining life of the wheelset must be performed after each wheelset turning. Refinement of the value of the residual resource of the wheelset must be performed after each control of the parameters of the wheelset in operation. A linear function can be used as a predictive function (Fig. 2). Despite the approximate nature of the prediction, an important parameter is the predicted rate of reduction in the rim thickness. Using the capabilities of modern information systems based on the regular collection and analysis of statistics on the geometric dimensions for each wheelset, it becomes possible to obtain an individual prediction of the resource before the wheelset changing. At each step of turning and checking the geometry of the wheelset, the remaining resource will be specified.

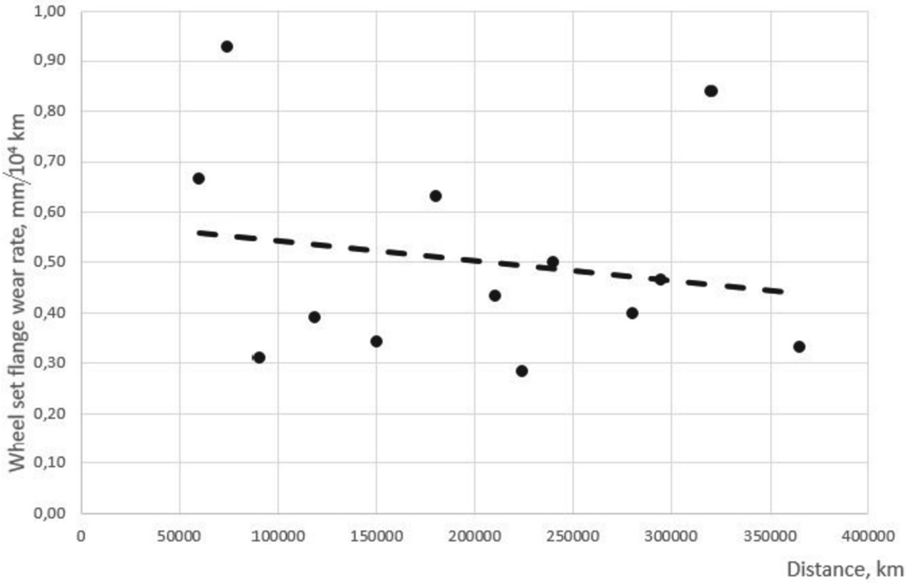

Fig. 1. Wheelset flange wear rates, where “points” is the wear data, “line” is the linear trend.

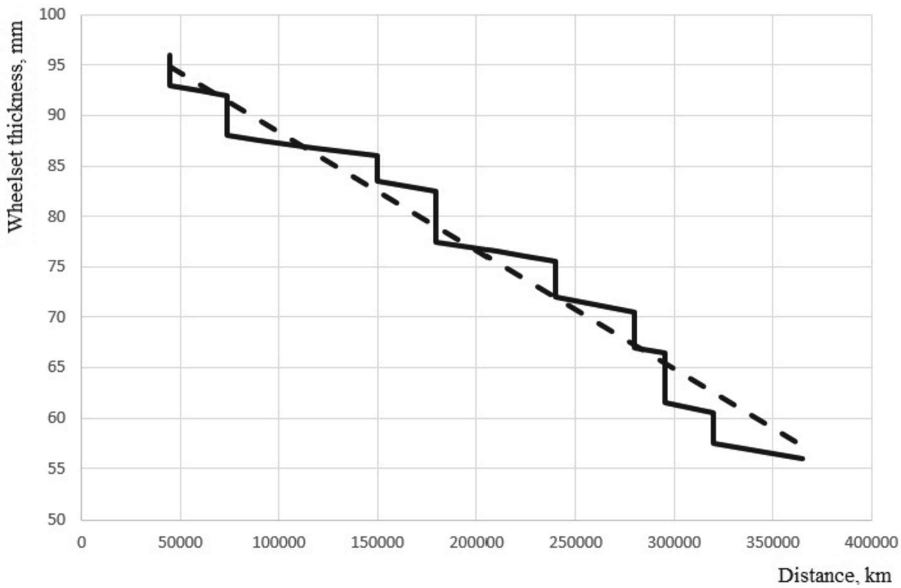

Fig. 2. Wear of the wheelset rim, because of turning, where “solid line” is measurement results, “dotted line” is the linear trend.

An example of the analysis of the collected data on rim wear and the results of defining the average wear rate of the rim for each wheelset for four electric locomotives is shown in Fig. 3.

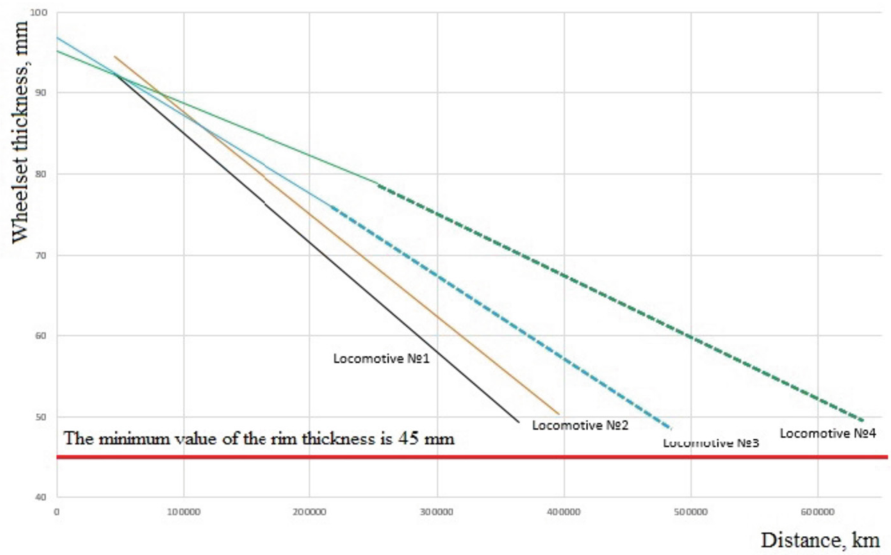

Fig. 3. The graph of the predicted wear of wheelset rims, where “solid line” is real wear, “dotted line” is predicted wear.

The graph (Fig. 3) shows the reduction in the wheelset rim thickness of the locomotive, relative to the mileage. Lines 1 and 2 are marked with a solid line, built based on real data from locomotives No. 1 and No. 2. Lines 3 and 4 for locomotive No. 3 and No. 4, respectively, consist of two parts. The solid line is real data, and the dashed line is predicted data, which is built on the basis of the collected turning and wear data. The predicted line is not constant, so each time the system receives new parameters, the predicted line will change due to the automatic recalculation of the system. The mileage of the electric locomotive, corresponding to the boundary value of the rim, is the point of intersection of the graph of the average wear rate with the horizontal line of the minimum rim thickness.

As one can see from the graph, during operation, the rim wear rate increases significantly, which is explained by an increase in the number of turnings, each turning significantly reduces the resource of the wheelset before changing.

Having analyzed the data, we can conclude that the information collected for each locomotive needs to be analyzed regarding to its individual parameters. Due to the regularity of data collection and automated analysis, it becomes possible to predict the setting of rolling stock for maintenance, therefore, to plan rationally the time of maintenance and the load on the enterprises’ infrastructure. It should be noted that timely monitoring and predicting the parameters of wheelsets can significantly affect the total amount of time required for the locomotive to be in operation. This in turn will lead to a decrease in operating costs for maintenance and an increase in the profit of the enterprise. An analysis of the data collected on the downtime of electric locomotives made it possible to define that during the operation of one locomotive, the idle time in waiting only for maintenance for wheelset turning is 10 days a year, which corresponds to the potential shortfall in profits of the enterprise.

The given example of predicting the residual life of a wheelset before its change shows the feasibility of using the RCM methodology for nodes whose wear has a linear or predetermined character.

4 Conclusions

When implementing the RCM methodology, it is obligatory to implement systematic monitoring of the operating parameters for the locomotive. Based on the analysis of the dynamics of the changes in operational parameters, the intervals for conducting control inspections, the periodicity period, and the size of maintenance and repair work are adjusted. RCM is considered to be optimal for a combination of several maintenance strategies, namely reactive maintenance, planned maintenance (based on operating time or time intervals), limiting condition-based maintenance, and preventive maintenance service. These maintenance strategies, instead of being applied separately, can be used simultaneously. This allows you to take advantage of the strengths of each strategy to minimize lifecycle costs.

It is most expedient to implement the RCM methodology for nodes whose failures are caused by wear and the law of failure development is known. Such nodes include wheelsets, brake pads, brushes for traction motors, etc.

The paper gives an example of an individual predicting the remaining resource (mileage before changing) of wheelsets for passenger electric locomotives ChS7. When performing the research, statistics were collected on the wear of wheelsets from the moment of the overhaul to the mileage of 350 and 400 thousand km. For two locomotives. It is also and for two other electric locomotives, in the range of up to 250 thousand km of mileage.

The analysis of the wear rate for flanges and rims of wheelsets in electric locomotives is carried out. The paper presents the results of the analysis of the wear of the first wheelset for each electric locomotive since the wear of the first wheelset defined the moment for setting the electric locomotive for maintenance with wheelset turning. The analysis showed uneven wear and different wear rates of wheelsets for different electric locomotives, despite the same operating area. It is shown that the main factor limiting the service life of the wheelset is the number of wheelsets turning, since in the process of turning the wheelset rim thickness in the electric locomotive is significantly reduced.

Using the proposed approach does not allow predicting for a long interval. However, it allows for ensuring safety, due to regular monitoring and predicting the remaining resource, efficiency, by reducing downtime in waiting for maintenance and increasing the completeness in the use of the wheelsets resource.

References

1. Ochkasov, O., Ocheretniuk, M., Skvireckas, R.: Approaches to the improving the locomotive fleet management system. In: Transport Means 2021: Proceedings of the 25th International Scientific Conference, pp. 1054–1058 (2021). https://transportmeans.ktu.edu/wp-content/uploads/sites/307/2018/02/Transport-Means-2021-Part-III.pdf
2. Lee, J., Ni, J., Singh, J., Jiang, B., Azamfar, M., Feng, J.: Intelligent maintenance systems and predictive manufacturing. ASME. J. Manuf. Sci. Eng. **142**(11), 110805 (2020). https://doi.org/10.1115/1.4047856
3. Bodnar, B., Ochkasov, O.: System choice of the technical maintenance of locomotives equipped with on-board diagnostic systems. In: Transport Means 2017: Proceedings of 21st International Conference, Juodkrante, Lithuania, 20–22 September 2017, Part I - pp. 43–47. Kaunas University of Technology, Kaunas (2017)
4. Bondar, B., Ockasov, O., Petrenko, V., Martishevskij, M.: Implementing intelligent monitoring of the technical condition of locomotive hydraulic transmissions. In: Prentkovskis, O., Yatskiv, I., Skačkauskas, P., Maruschak, P., Karpenko, M. (eds.) TRANSBALTICA 2022. LNITI, pp. 726–736. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-25863-3_70
5. Tartakovskyi, E., Ustenko, O., Puzyr, V., Datsun, Y.: Systems approach to the organization of locomotive maintenance on Ukraine railways. In: Sładkowski, A. (ed.) Rail Transport—Systems Approach. SSDC, vol. 87, pp. 217–236. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-51502-1_5
6. Grencik, J., Poprocký, R., Galliková, J., Volna, P.: Use of risk assessment methods in maintenance for more reliable rolling stock operation. In: MATEC Web of Conferences (2018)
7. Xu, S., Chen, C., Lin, Z., Zhang, X., Dai, J., Liu, L.: Review and prospect of maintenance technology for traction system of high-speed train. Transp. Saf. Environ. **3**(3) (2021)
8. Bulakh, M., Okorokov, A., Baranovskyi, D.: Risk system and railway safety. Paper Presented at the IOP Conference Series: Earth and Environmental Science (2021)
9. Afefy, I.H.: Reliability-centered maintenance methodology and application: a case study. Engineering **2**(11), 863–873 (2010)
10. Carretero, J., et al.: Applying RCM in large scale systems: a case study with railway networks. Reliab. Eng. Syst. Saf. **82**(3), 257–273 (2003)
11. Rezvanizaniani, S., Valibeigloo, M., Asghari, M., Barabady, J., Kumar, U.: Reliability centered maintenance for rolling stock: a case study in coaches' wheel sets of passenger trains of Iranian railway. In: 2008 IEEE International Conference on Industrial Engineering and Engineering Management, pp. 516–520 (2008)
12. Hussain, M.: Enhancing Operational Efficiency with Reliability Centered Maintenance (RCM) (2023)
13. Cotaina, N., et al.: Study of Existing Reliability Centered Maintenance (RCM) Approaches Used in Different Industries (2000)
14. Cheng, H., Cao, Y., Wang, J., Zhang, W., Zeng, H.: A preventive, opportunistic maintenance strategy for the catenary system of high-speed railways based on reliability. Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit **234**(10), 1149–1155 (2020)
15. Wei, D.I.: Reliability maintainability and maintenance information management of locomotive and car. J. Beijing Jiaotong Univ. **31**(6), 15–17 (2007)
16. Singh, S.B., Suresha, R., Sachidananda, K.H.: Reliability centered maintenance used in metro railways. J. Eur. des Syst. Automatises **53**(1), 11–19 (2020)
17. Bodnar, B.E., Ochkasov, O.B., Bodnar, E.B., Hryshechkina, T.S., Ocheretnyuk, M.V.: Simulation of locomotive repair organization by the methods of queue systems theory. Наука та прогрес транспорту (5), 28–40 (2018)
18. Rules of technical operation of railways of Ukraine, 256 p. Transport of Ukraine, Kyiv (1995)