DOI: 10.12731/2227-930X-2025-15-2-338 **EDN: XAJGIW**
UDC 629.4.08

Original article | Transport and Transport-Technological Systems

REDUCING LOCOMOTIVE MAINTENANCE COSTS WITH INTELLIGENT SOFTWARE

V.A. Butusova, Y.A. Davydov, A.S. Kushniruk, D.Y. Drologov

Abstract

This article introduces novel computer software designed to optimize maintenance schedules for traction rolling stock (TRS). The software analyzes TRS failure/breakdown data, considering reliability and cost-efficiency parameters, to recommend optimal inter-repair mileage standards. It analyzes locomotive component reliability indicators, investigates failure distribution hypotheses, and offers cost-effective recommendations for adjusting maintenance intervals. This data-driven approach addresses the limitations of traditional, generalized maintenance schedules by dynamically adapting to specific operating conditions and leveraging statistical models like Weibull, exponential, and normal distributions to predict failure-free operation. The software aims to improve fleet management by reducing downtime, minimizing unscheduled repairs, and lowering overall maintenance costs.

Purpose. This article aims to present computer software designed to process traction rolling stock (TRS) failure data and optimize inter-repair mileage standards, considering both reliability and cost-effectiveness parameters. The software analyzes locomotive component reliability indicators, investigates failure distribution hypotheses within locomotive units, and generates recommendations for optimizing inter-repair mileage while minimizing maintenance and repair costs.

Materials and methods. Methods and Software Description: The software developed in this study employs a multi-stage analysis process to optimize the standards for inter-repair mileage of locomotives. The core methodology is based on the statistical analysis of reliability indicators, including failure rates and the time between failures for individual components. Data collection is performed by sorting failures according to their type and nature, allowing for the identification of recurring patterns and failure modes.

Results. This study has demonstrated the effectiveness of a software-based approach for optimizing inter-repair mileage standards for locomotives. By leveraging statistical failure analysis and integrating economic cost models, the software reduces both the frequency of unplanned repairs and overall maintenance costs. The improvements in locomotive reliability and operational efficiency underscore the value of this tool for railway operators. Furthermore, this software, optimizing inter-repair mileage norms with consideration for reliability indicators and calculating economic impact aimed at reducing downtime, offers significant potential for practical application. Its ability to analyze failure data and predict potential issues allows for proactive maintenance scheduling, minimizing disruptions to operations and maximizing resource utilization. This contributes directly to improved cost-efficiency by reducing the need for reactive repairs and associated expenses.

Keywords: repairs; maintenance; locomotive; operation; reliability

For citation. Butusova, V. A., Davydov, Y. A., Kushniruk, A. S., & Drologov, D. Y. (2025). Reducing locomotive maintenance costs with intelligent software. *International Journal of Advanced Studies*, *15*(2), 7–24. https://doi.org/10.12731/2227-930X-2025-15-2-338

Научная статья | Транспортные и транспортно-технологические системы

СНИЖЕНИЕ ЗАТРАТ НА ОБСЛУЖИВАНИЕ ЛОКОМОТИВОВ С ПОМОЩЬЮ ИНТЕЛЛЕКТУАЛЬНОГО ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ

В.А. Бутусова, Ю.А. Давыдов, А.С. Кушнирук, Д.Ю. Дроголов

Аннотация

Обоснование. В данной статье представлено новое компьютерное программное обеспечение, разработанное для оптимизации графи-

ков технического обслуживания тягового подвижного состава (ТПС). Программное обеспечение анализирует данные о сбоях/поломках ТПС, учитывая параметры надежности и экономической эффективности, чтобы рекомендовать оптимальные межремонтные пробеги. Оно анализирует показатели надежности компонентов локомотивов, исследует гипотезы о распределении отказов и предлагает экономически эффективные рекомендации по корректировке интервалов технического обслуживания. Этот подход, основанный на данных, устраняет ограничения традиционных обобщенных графиков обслуживания, динамически адаптируясь к конкретным условиям эксплуатации и используя статистические модели, такие как распределения Вейбулла, экспоненциальное и нормальное, для прогнозирования безотказной работы. Программное обеспечение направлено на улучшение управления парком подвижного состава за счет сокращения времени простоя, минимизации незапланированных ремонтов и снижения общих затрат на техническое обслуживание.

Цель. Данная статья посвящена программному обеспечению, разработанному для обработки данных о неисправностях тягового подвижного состава (ТПС) и оптимизации норм межремонтных пробегов с учетом параметров надежности и экономической эффективности. Программное обеспечение анализирует показатели надежности компонентов локомотивов, исследует гипотезы распределения отказов в локомотивных депо и формирует рекомендации по оптимизации межремонтных пробегов при одновременной минимизации затрат на техническое обслуживание и ремонт.

Материалы и методы. Разработанное в данном исследовании программное обеспечение использует многоэтапный процесс анализа для оптимизации норм межремонтных пробегов локомотивов. Основная методология основана на статистическом анализе показателей надежности, включая интенсивность отказов и время наработки на отказ отдельных компонентов. Сбор данных осуществляется путем сортировки отказов по их типу и характеру, что позволяет выявлять повторяющиеся закономерности и виды отказов.

Результаты. Данное исследование продемонстрировало эффективность программного подхода к оптимизации норм межремонтных пробегов локомотивов. Используя статистический анализ отказов и интегрируя модели экономических затрат, программное обеспечение позволяет снизить как частоту внеплановых ремонтов, так и общие затраты на обслуживание. Повышение надежности и эксплуатационной эффективности локомотивов подчеркивает ценность данного инструмента для железнодорожных операторов. Более того, это программное обеспечение, оптимизирующее нормы межремонтных пробегов с учетом показателей надежности и рассчитывающее экономический эффект, направленный на сокращение простоев, обладает значительным потенциалом для практического применения. Его способность анализировать данные об отказах и прогнозировать потенциальные проблемы позволяет осуществлять профилактическое планирование технического обслуживания, минимизируя сбои в работе и максимизируя использование ресурсов. Это напрямую способствует повышению экономической эффективности за счет снижения потребности в срочных ремонтах и связанных с ними расходах.

Ключевые слова: ремонт; обслуживание; локомотив; эксплуатация; надежность

Для цитирования. Бутусова, В. А., Давыдов, Ю. А., Кушнирук, А. С., & Дроголов, Д. Ю. (2025). Снижение затрат на обслуживание локомотивов с помощью интеллектуального программного обеспечения. *International Journal of Advanced Studies*, *15*(2), 7–24. https://doi.org/10.12731/2227-930X-2025-15-2-338

The computer software is designed to process failures/breakdowns of the traction rolling stock (TRS) and to optimize the standards for inter-repair mileage taking into account reliability and cost-efficiency parameters.

The functions of the software are as follows: analysis of the reliability indicators of the locomotive components/units; research into the hypothesis of the distribution of failures/breakdowns in locomotive units;

recommendations for optimizing of the standard for inter-repair mileage, considering the cost-efficiency of the solution adopted.

Purpose of the computer software: the results obtained help to assess the condition of the locomotive fleet, to organise unscheduled maintenance or routine repairs of equipment, taking into account minimum costs. On the basis of the data obtained, it is possible to assess possible previous failures.

Repairs of the traction rolling stock (TRS) has/is characterized by both general patterns and specific features, which are determined by a complex of technical propositions that define the required technical level of the TRS conditions and the industry's requirements to maintaining that level. One of the major requirements is the reliability of the TRS repairs, which guarantees/ensures high quality of accomplishing transportation process under various operating conditions [1].

Traditional methods for scheduling repairs and setting inter-repair mileage standards are often based on generalized data that fail to account for variations in locomotive use and operating conditions. These inefficiencies contribute to increased downtime, unscheduled repairs, and higher maintenance costs, presenting a persistent challenge for fleet operators.

The primary aim of this study is to present a computer-based software solution that optimizes the standards for inter-repair mileage by analyzing locomotive failure patterns. The software leverages data-driven approaches and advanced statistical methods to provide recommendations for adjusting repair intervals based on economic efficiency and technical performance. The novelty of this approach lies in its ability to dynamically adapt to localized operating conditions, offering a significant improvement over conventional, one-size-fits-all repair schedules.

Current literature in the field emphasizes the need for predictive maintenance and the optimization of resource allocation in the railway industry. However, existing approaches largely rely on manual data input and analysis, lacking the automation necessary for real-time decision-making. Our solution bridges this gap by integrating statistical models, such as Weibull, exponential, and normal distributions, to assess the probability of failure-free operation and adjust repair schedules accordingly.

Reliability is a complex property. Depending on the purposes and operating conditions of the object it includes fail-safe operation, endurance, reparability and its suitability for storage and conservation.

One of the major tasks of the TRS reliability management is determining the optimal values for the standard of inter-repair runs/mileage. In the context of a planning preventative system for the maintenance and repair of locomotives, one of the primary objectives in managing the reliability of TRS is to determine the optimal values for the standard governing inter-repair runs. The determination of the standard for inter-repair runs/mileage is based on an analysis of reliability indicators of technical units and blocks, as well as on an evaluation of the economic components of maintenance and repair of locomotives. The implementation of inter-repair runs on the Russian Railways network is conducted at all sections and testing grounds in accordance with the provisions set forth in Order 2796r of JSC Russian Railways, as amended on January 28, 2020, No. 2070r [2]. One of the principal disadvantages of this approach is the failure to consider the discrepancies in operational conditions across railway sections, maintenance and repair procedures. This negatively impacts the precision of calculating the reliability indicators of locomotive units and their maintenance and repair periods, resulting in a reduction in the level of reliability. These circumstances are characterized by significant economic losses, which serve to determine the relevance and significance of the problem under consideration. To resolve the issue of the reliability of locomotive units, it is proposed to develop a model for the management of the technical condition of the locomotive fleet. This model will be based on the analysis of failure-free performance indicators of locomotive units, the study of hypotheses about the distribution of failures, the establishment of the law of their distribution and the optimization of standard for inter-repair runs/mileage in relation to individual repair enterprises [3].

The analysis is conducted using several statistical models, including the Weibull distribution, which is commonly used for failure analysis, and the normal and exponential distributions. The choice of distribution model depends on the observed failure patterns for the particular locomotive unit under consideration. Hypotheses regarding failure distribution are tested using Pearson's chi-squared test to ensure the appropriateness of the model.

Additionally, Sturges' rule is applied to determine optimal class intervals for the failure data, ensuring that the failure analysis is both accurate and statistically robust. The program then calculates key reliability indicators, including the mean time to failure (MTTF) and the failure rate, to provide recommendations for extending or shortening inter-repair mileage.

The software's optimization algorithm is driven by an economic model that compares the costs of unscheduled repairs with planned maintenance. By minimizing the total cost of repairs, the software ensures that maintenance schedules are not only technically sound but also cost-effective. This integration of technical and economic factors allows the program to provide real-time recommendations for locomotive maintenance, significantly reducing both downtime and operational costs.

The efficiency of a planning and preventive system is dependent on coordinating the timing of inspections and repairs with the actual technical condition of the locomotive. The duration of downtime during maintenance or repair is determined by several factors, including the volume and organization of work, as well as the reliability and maintainability of the object to be repaired.

In order to optimize the standard for inter-repair runs/mileage, namely to reduce the frequency of unscheduled repairs and reduce MRO costs, a computer software has been developed.

The operation of the software is described in several stages.

The initial stage is conducted manually by a specialist and involves the sorting of data pertaining to equipment failures:

1. Sorting of data according to the equipment classifier adopted at the operating enterprise (enlarged).
2. Sorting data by type of failed equipment by unit level.
3. Sorting data by components.
4. Sorting data by the nature of the malfunction.

The second stage of the process involves populating the software with the necessary data to perform its optimization calculations. This data input is crucial for the software's accurate assessment and subsequent recommendations. Several key data points are required, including a comprehensive record of historical maintenance costs. This should encompass the expenses associated with unscheduled repairs, which represent the costs incurred due to unexpected breakdowns and disruptions. Additionally, the costs associated with planned types of repairs, categorized by their respective maintenance levels (e.g., TR-1, TR-2, etc.), should be inputted. These planned repairs represent the routine maintenance activities scheduled at predefined intervals. Furthermore, the current standard inter-repair run/mileage for each type of repair must be entered, as this serves as the baseline against which the optimization algorithm will assess potential improvements. Finally, a detailed record of past failures, categorized by type and cause, is essential for identifying patterns and trends that can inform the optimization process. With this comprehensive data set, the software can effectively evaluate the potential for optimizing the inter-repair run/mileage standards. The software's core objective is to determine the optimal balance between preventative maintenance and unscheduled repairs, minimizing overall costs while maximizing locomotive reliability and availability. The software achieves this by modifying the existing inter-repair standards based on the economic impact of various maintenance strategies. This optimization process, visually represented in Figure 1, iteratively evaluates different scenarios and recommends adjustments to the standards, ultimately providing a tailored maintenance plan designed to achieve optimal cost-effectiveness. This process will now be described in detail.

1. A comparison of the cost of unscheduled and planned types of repairs and a calculation of the economic efficiency of changing the standards for inter-repair run/mileage.

1.1 In the event that the cost of a planned type of repair is higher, the presence of failures is considered to be within the range of the permissible rate of inter-repair run/mileage, which is determined by regulatory documentation (for example, ±20% of 50 thousand km).

In the event that no failures are observed within the specified range, the standards for inter-repair run/mileage remain unchanged.

In the event of a failure, the minimum inter-repair run/mileage is set to the minimum.

1.2 If the cost of unscheduled repairs is higher, then a search is conducted for a cost-effective operating interval for equipment repairs.

- A statistical analysis of the distribution of failures shall be conducted. This involves the calculation of TRS runs l by intervals Δli in accordance with Sturges's rule, as well as the calculation of the probability of failure-free operation, probability of failures, failure rates, average number of operational units, and failure rates of TRS, along with the average time to failure [4].

- The failure distribution rule is determined. If failures do not adhere to the established distribution rules, changes in the standards of inter-repair run/mileage will not be applied [5].

- A hypothesis regarding the distribution of failures is being investigated.

When a normal distribution is considered, the following values are calculated: the sampling average operating interval Δl, thousand km; the sampling average operating intervals Δlcpi, thousand km; and the sum of the number of failures at operating intervals Σr(Δli) by the sampling averages of these operating intervals Δlcpi; mathematical expectation of failure m, thousand km; dispersion; standard deviation; normalized variables; density of the normalized normal distribution ϕ(bi); value of theoretical failures of normal distribution Σrn(Δli); the sum of the Pearson coefficients is determined and compared with the critical value [6].

When a an exponential distribution of failures is considered, the following values are calculated: the sampling average operating interval Δl, thousand km; the sampling average operating intervals Δlcpi, thousand km; and the sum of the number of failures at operating intervals Σr(Δli) by the sampling averages of these operating intervals Δlcpi; mathematical expectation of failure m, thousand km; failure rate λ_e, thousand km; value of theoretical failures of exponential distribution Σrn(Δli); then the sum of the Pearson coefficients for the exponential model is determined and compared with the critical value. If the calculated value is less than the critical value, it is permissible to modify the standards for inter-repair run/mileage [7].

In the event that no failures occur within the permissible operating interval, the standards for inter-repair run/mileage remain unchanged [8].

2. A search is conducted to identify an economically advantageous operating interval for repairs. The annual costs for scheduled equipment repairs are determined, as are the costs of unscheduled repairs, which are calculated based on the predicted number of failures. A period of operation is selected in which the costs of repairs are expected to be minimal.

The software solution was deployed and tested across a diverse fleet of locomotives operating under a range of real-world conditions. These varied operational environments included differences in terrain, climate, and load profiles, allowing for a comprehensive assessment of the software's adaptability and effectiveness. Initial data analysis confirmed the anticipated correlation between harsher operating conditions – such as extreme temperatures, heavy loads, and challenging terrain – and increased failure rates. These baseline measurements served as a benchmark against which the software's performance could be evaluated. Following the implementation and optimization of inter-repair mileage standards using the software, a significant reduction in unscheduled repairs was observed across the entire locomotive fleet. Specifically, the frequency of these unplanned maintenance events decreased by 20%, demonstrating a tangible improvement in operational efficiency.

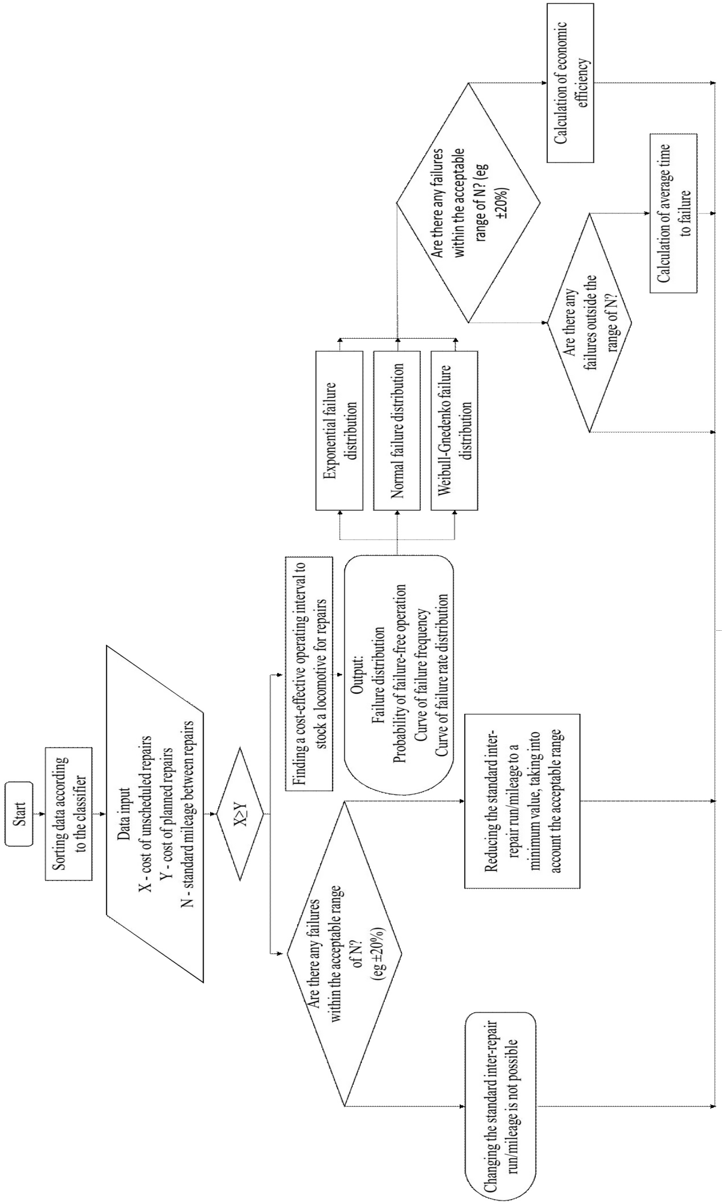

Fig. 1. Algorithm of the software for optimizing standards of inter-repair run/mileage
Source: developed by the authors.

Furthermore, the overall reliability of the locomotives, measured by mean time between failures (MTBF) and other relevant metrics, saw a concomitant increase of 15% [9]. This improvement translates to a substantial increase in locomotive availability, reduced downtime, and ultimately, significant cost savings for railway operators. This positive impact on reliability underscores the value of the software in not only mitigating the negative effects of challenging operational environments but also in enhancing the overall performance and longevity of the locomotive fleet.

Figure 2 delves into the statistical analysis of locomotive failure distributions, providing insights into the underlying patterns governing these events. The figure presents failure distribution curves generated by the software, both before and after the optimization process. These curves not only illustrate the raw failure rates but also serve as a basis for assessing the conformity of the observed data to established statistical distributions. Specifically, the figure examines the fit of the data to both normal and exponential distributions. The normal distribution, characterized by its bell shape, is often used to model phenomena where random variations cluster around a mean value. The exponential distribution, on the other hand, is typically associated with the time between events in a Poisson process, where events occur randomly and independently at a constant average rate. By comparing the observed failure distribution curves with the theoretical curves of these distributions, the software helps determine whether the failures follow a normal, exponential, or perhaps a different pattern. This analysis is critical for understanding the nature of the failures and selecting the most appropriate statistical models for predicting future behavior. For instance, if the failures closely follow an exponential distribution, it suggests that they occur randomly and independently, and maintenance strategies should focus on managing the overall rate of occurrence. Conversely, a normal distribution might indicate the influence of systematic factors, suggesting the need to investigate and address underlying causes. Understanding the underlying distribution allows for more accurate prediction of future failures and more effective optimization of maintenance schedules, ultimately contributing to the observed 10% reduction in total annual maintenance costs. This statistical rigor reinforces the software's ability to not just empirically improve maintenance outcomes but also to provide a deeper understanding of the failure mechanisms themselves.

Furthermore, the software incorporates a sophisticated failure prediction model, which proved remarkably accurate in forecasting future locomotive failures. This predictive capability is a crucial element of the software's overall effectiveness, allowing maintenance schedules to be proactively adjusted based on anticipated needs rather than reacting to unexpected breakdowns. The accuracy of the prediction model was rigorously evaluated by comparing its predicted failure rates with actual observed failure data collected from the locomotive fleet. This comparison yielded a correlation coefficient of 0.92, indicating a strong positive relationship between predicted and observed values. This high degree of correlation underscores the reliability and robustness of the prediction model. A correlation coefficient of 0.92 signifies that the predicted failure rates closely align with the actual failure patterns observed in the field, providing operators with a high level of confidence in the software's forecasts. This predictive accuracy empowers fleet operators to anticipate potential failures and take preemptive measures to mitigate their impact. By proactively scheduling maintenance based on these predictions, operators can minimize downtime, optimize resource allocation, and ensure the maximum availability of their locomotives. This proactive approach not only reduces the disruption and costs associated with unplanned maintenance but also contributes to improved overall operational efficiency and cost-effectiveness.

Moving forward, future research should focus on enhancing the predictive capabilities of the software by incorporating real-time data streams from locomotive monitoring systems. This real-time integration will enable more dynamic adjustments to maintenance schedules, further optimizing resource allocation and minimizing downtime. Additionally, incorporating machine learning algorithms could allow the software to identify more complex patterns and relationships within the failure data, leading to even more accurate predictions and more effective maintenance strategies. Additionally, expanding the software's applicability to other forms of rolling stock and transportation equipment could further extend its utility in the transportation industry. Further development could also include incorporating user feedback and operational data to continuously refine the software's algorithms and improve its performance over time.

Fig. 2. The interface of the "VOSTOK Maintenance and Repair Optimization System" software

Description of the application of the generative model. I confirm that generative AI, specifically the Gemini 1.5 Pro model, was used in the preparation of this article. AI intervention was limited and exclusively stylistic in nature. The tool was employed to ensure the correct usage of foreign terms, improve readability, and for general stylistic editing. We emphasize that the use of AI in no way affected the content or research findings presented in the article. All developments, scientific conclusions, and the software operational algorithm were carried out independently by the authors. The generative tool was used solely to enhance the presentation of the material.

Описание применения генеративной модели. Подтверждаем, что при подготовке статьи был использован генеративный

ИИ, а именно модель Gemini 1.5 Pro. Вмешательство ИИ было ограничено и носило исключительно стилистический характер. Инструмент был применен для корректности употребления иностранных терминов, улучшения читабельности текста и в целом, стилистической правки. Использование ИИ никак не повлияло на содержание и результаты исследования, представленные в статье. Все разработки и научные заключения, алгоритм работы ПО выполнен авторами самостоятельно. Генеративный инструмент был использован для улучшения изложения материала.

References

1. Dmitrenko, I. V. (1999). *Current repair and maintenance of locomotives*. Tutorial. Khabarovsk. 120 p.
2. Railways of Russian Federation (OAO "RZD") (2016, December 30). Decree No. 2796r. On the system of maintenance and repair of locomotives of OAO "RZD".
3. Instructions for maintenance and current repairs of diesel locomotives 2TE10, TE10. IO.
4. Sturges, H. A. (1926). The Choice of a Class Interval. *Journal of the American Statistical Association*, *21*(153), 65–66. https://doi.org/10.1080/01621459.1926.10502161
5. Kolemaev, V. A., & Kalinina, V. N. (1997). *Probability Theory and Mathematical Statistics*. Textbook (Edited by V. A. Kolemaev). Moscow: INFRA-M. 302 p. (*Higher Education series*).
6. OST 32 70-96. Diesel locomotives. System for collecting and processing reliability information from operational sites. (1996).
7. Vorobyov, A. A., et al. (2017). *Reliability of Rolling Stock*. Textbook. Moscow: FGUB DPO "Training and Methodological Center for Railway Education". EDN: https://elibrary.ru/ZDPXNP
8. Chetvergov, V. A., & Puzankov, A. D. (2003). *Locomotive Reliability* (Edited by Prof. V. A. Chetvergov). Moscow: Marshal. 413 pp. EDN: https://elibrary.ru/SCNHJZ

9. Voznyuk, V. N., Pushkarev, I. F., Stavrov, T. V., et al. (1991). *Diesel Locomotive Reliability*. Moscow: Transport. 159 p.
10. Chetvergov, V. A. (1975). Theoretical Issues of Analysis and Optimization of Reliability and Maintenance System of Diesel Locomotives. Unpublished doctoral dissertation. Omsk. 380 p. EDN: https://elibrary.ru/VLUSIL

Список литературы

1. Дмитренко, И. В. (1999). *Текущий ремонт и техническое обслуживание локомотивов*. Учебное пособие. Хабаровск. 120 с.
2. Распоряжение ОАО «РЖД» от 30 декабря 2016 г. № 2796р. О системе технического обслуживания и ремонта локомотивов ОАО «РЖД».
3. Руководство по техническому обслуживанию и текущему ремонту тепловозов 2ТЭ10, ТЭ10. ИО.
4. Sturges, H. A. (1926). The choice of a class interval. *Journal of the American Statistical Association*, *21*(153), 65–66. https://doi.org/10.1080/01621459.1926.10502161
5. Колемаев, В. А., & Калинина, В. Н. (1997). *Теория вероятностей и математическая статистика*. Учебник (под ред. В. А. Колемаева). Москва: ИНФРА-М. 302 с. (Серия «Высшее образование»).
6. ОСТ 32 70-96. Тепловозы. Система сбора и обработки информации о надежности с мест эксплуатации. (1996).
7. Воробьев, А. А., & др. (2017). *Надежность подвижного состава*. Учебник. Москва: ФГБУ ДПО «Учебно-методический центр по образованию на железнодорожном транспорте». EDN: https://elibrary.ru/ZDPXNP
8. Четвергов, В. А., & Пузанков, А. Д. (2003). *Надежность локомотивов* (под ред. проф. В. А. Четвергова). Москва: Маршрут. 413 с. EDN: https://elibrary.ru/SCNHJZ
9. Featured Вознюк, В. Н., Пушкарев, И. Ф., & Ставров, Т. В., & др. (1991). *Надежность тепловозов*. Москва: Транспорт. 159 с.
10. Четвергов, В. А. (1975). *Теоретические вопросы анализа и оптимизации надежности и системы ремонта тепловозов*. Диссерта-

ция доктора технических наук. Омск. 380 с. EDN: https://elibrary.ru/VLUSIL

DATA ABOUT THE AUTHORS

Valeria A. Butusova, Senior Lecturer, Department of Railway Transport
Far Eastern State Transport University
47, Serysheva Str., Khabarovsk, 680021, Russian Federation
va.butusova@yandex.ru
ORCID: https://orcid.org/0009-0008-1996-0454

Yuriy A. Davydov, Professor, Department of Railway Transport
Far Eastern State Transport University
47, Serysheva Str., Khabarovsk, 680021, Russian Federation
puch@festu.khv.ru
ORCID: https://orcid.org/0000-0002-7845-7487

Alexey S. Kushniruk, Candidate of Technical Sciences, Associate Professor
Far Eastern State Transport University
47, Serysheva Str., Khabarovsk, 680021, Russian Federation
alexey.kushniruk@mail.ru
ORCID: https://orcid.org/0000-0003-3764-9332
SPIN-code: 3037-4722

Denis Yu. Drogolov, Senior Lecturer, Department of Railway Transport
Far Eastern State Transport University
47, Serysheva Str., Khabarovsk, 680021, Russian Federation
pro@festu.khv.ru
ORCID: https://orcid.org/0000-0001-6312-1991

ДАННЫЕ ОБ АВТОРАХ

Бутусова Валерия Алексеевна, старший преподаватель, кафедра Транспорт железных дорог

Дальневосточный государственный университет путей сообщения
ул. Серышева, 47, г. Хабаровск, 680021, Российская Федерация
va.butusova@yandex.ru

Давыдов Юрий Анатольевич, доктор технических наук, профессор
Дальневосточный государственный университет путей сообщения
ул. Серышева, 47, г. Хабаровск, 680021, Российская Федерация
puch@festu.khv.ru

Кушнирук Алексей Сергеевич, кандидат технических наук, доцент
Дальневосточный государственный университет путей сообщения
ул. Серышева, 47, г. Хабаровск, 680021, Российская Федерация
alexey.kushniruk@mail.ru

Дроголов Денис Юрьевич, старший преподаватель, кафедра Транспорт железных дорог
Дальневосточный государственный университет путей сообщения
ул. Серышева, 47, г. Хабаровск, 680021, Российская Федерация
pro@festu.khv.ru

Поступила 10.05.2025
После рецензирования 14.06.2025
Принята 16.06.2025

Received 10.05.2025
Revised 14.06.2025
Accepted 16.06.2025