Assessment of the Service Life of TE33A Series Locomotive Wheelset Components Using Statistical Analysis Methods

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***Abstract*—This paper presents a methodology for assessing wear indicators and the service life of wheelsets of TE33A diesel locomotives operated on the Kazakhstan railway network, based on their dimensional parameters. To evaluate the reliability of wheelsets under operating conditions, the service life corresponding to a 90% probability of failure-free operation was determined and compared with existing regulatory requirements. The rolling surface thickness and flange profile were selected as the key parameters influencing wheelset reliability and determining the operational service life. It should be noted that TE33A locomotives are equipped with monoblock (unbandaged) wheelsets; therefore, once the service life is exhausted, the wheels are subject to complete replacement. The study applies a mathematical assessment methodology based on reliability theory to assess the service life of wheelset components. Methods of mathematical statistics were used to analyze failure-related operational data. The distribution of time to failure was approximated using the Pearson distribution, which made it possible to estimate the mean time to failure, variance, and other reliability characteristics. The obtained results allow for the identification of key parameters affecting wear and provide a basis for determining maintenance and repair intervals.**

***Keywords*—railway transport reliability, wheelset service life, reliability theory, mathematical statistics, maintenance, failure prediction**

I. Introduction

Railway transport requirements necessitate a high level of reliability for rolling stock. Throughout the entire service life of locomotives, particular attention must be paid to maintaining their operational capability over extended periods. To ensure the safe and efficient operation of rolling stock, continuous monitoring of the technical condition of locomotive is required. Special emphasis is placed on safety-critical parameters of wheelsets, since their premature wear or defects significantly increase operational risks. Wheelsets are among the most critical components of rolling stock and are characterized by a high failure rate. Therefore, parameters such as tread thickness, flange profile, and wheel condition require regular monitoring.

Scheduled maintenance and repair of rolling stock are planned based on the wear level of wheelsets. However, unexpected defects may occur in wheelsets, which can lead to a reduction in operational safety. Continuous monitoring of wheelset parameters allows potential failures and emergency situations to be prevented. Defects caused by external factors—such as wheel flats, spalling, and surface cavities—can significantly degrade the condition of wheelsets. These defects may result from violations of locomotive operating conditions, non-compliance with maintenance standards during scheduled maintenance, and other factors. To prevent such situations, it is necessary to develop effective methods for predicting the service life of wheelsets [1].

The paper provides a review of research gaps related to the wheelset operation, including the assessment of wear processes and evaluation of the wear condition of wheelset components. The reviewed topics include the following:

- The influence of new materials and technologies on increasing wheelset service life. The development of advanced materials and manufacturing technologies for wheelsets requires continuous updating of wheel wear models and criteria for evaluating their service life [2].
- Consideration of nonlinear effects in wheel wear processes. Wear of wheelset components may exhibit nonlinear behavior, which significantly complicates the development of accurate predictive models [3].
- Impact of random factors on wheelset wear. Random factors such as manufacturing defects, uneven load distribution, and other operational irregularities can

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have a substantial effect on the service life of wheelset components [4].

- Prediction of the residual service life of wheelsets. Accurate prediction of the residual life of wheelset components is a complex task that requires consideration of multiple influencing factors and the application of modern methods using integrated software systems [5].

The scientific novelty of the study lies in the development of a comprehensive methodology for assessing wheelset service life. The proposed approach is based on reliability theory and mathematical statistics and uses real operational measurement data obtained from TE33A locomotive wheelsets. The developed methodology allows for the consideration of the nonlinear nature of wear processes, variability in operating conditions, and the influence of random factors. This allows for increased accuracy of the results and improves prediction quality compared to existing traditional calculation methods.

Additionally, study identified the main critical parameters that have the greatest impact on the reliability of wheelsets, and their effect on the technical condition was quantitatively assessed. The proposed approach allows for an accurate assessment of the remaining service life of wheelsets and the optimization of the maintenance system. The universality of the methodology enables its adaptation and application to other types of rolling stock and various components. These features fully substantiate the scientific novelty of the article from both theoretical and practical standpoints.

The practical significance of the study is based on its applicability to maintenance optimization processes. The proposed method enables more accurate prediction of wheelset failure times, which facilitates the optimization of scheduled maintenance, reduces the likelihood of unscheduled downtime, and improves the operational efficiency of rolling stock. In terms of enhancing traffic safety, timely replacement of worn wheelset components contributes to improved operational safety and, consequently, to a reduction in the risk of emergency situations.

The assessment of wheelset service life was performed using reliability theory and statistical methods. This approach ensured more accurate results and enabled a reliable evaluation of key parameters. In addition, the identification of critical parameters influencing wheelset wear makes it possible to focus on the most vulnerable structural elements and to develop targeted reinforcement or mitigation measures. The applied methodologies increase the scientific value of the study. Furthermore, the proposed approach can be extended to assess the service life of other types of rolling stock and various components. The conclusions presented in the paper are based on rigorous mathematical analysis of experimental and operational data.

The main objective of this study is to obtain reliable and well-founded results through the following specific tasks:

- To perform measurements of the wheelset parameters of TE33A diesel locomotives and to develop a methodology for assessing wheelset service life based on the acquired measurement data.
- To identify the key parameters influencing wheelset wear and to evaluate their impact on reliability characteristics.
- To develop recommendations for optimizing maintenance strategies for rolling stock based on the obtained results.

II. Literature Review

Ensuring safe operation in rail transport is directly linked to the reliable functioning of rolling stock. The technical condition of the wheelsets, one of the main assemblies of locomotives, significantly affects train movement safety [3, 6]. Therefore, in scientific literature, the study of wheelset wear, assessment of their technical condition, and prediction of their service life are considered key research areas. Many studies indicate that the premature wear of wheelsets leads to an increase in unscheduled maintenance, higher operating costs, and a decrease in operational safety.

One line of research is dedicated to the application of new materials and modern technologies in wheelset manufacturing [1, 2, 7]. In recent years, opportunities to increase the service life of wheels by using high-strength alloys, introducing new heat treatment methods, and improving manufacturing processes have been actively researched. However, since the introduction of new materials changes the nature of wear processes, there is a need to constantly update the models and calculation methods for their evaluation.

Another issue widely discussed in the scientific literature is the nonlinear nature of the wear process of wheelsets [3, 4, 8]. The diversity of operating conditions, variations in dynamic loads, and the characteristics of railway infrastructure lead to a non-constant wear rate. This complicates the application of classical linear models and requires the use of complex mathematical methods and probabilistic-statistical models. For this reason, developing accurate prediction models remains a pressing task in current research.

Moreover, the influence of random factors on the wheelset service life is of particular importance. Factors such as production defects, material quality variations, uneven load distribution, and changes in operating modes significantly affect the wear process. Literature sources indicate that calculations performed without considering such factors may result in low prediction accuracy. Therefore, current scientific research is prioritizing the development of methods that account for random effects [5, 9].

The problem of predicting the residual service life is also the subject of numerous studies. In this area, reliability theory, probabilistic models, statistical data processing methods, and specialized software systems are used. However, practical methodologies based on actual operational measurements and suitable for industrial application have not been sufficiently developed. There remains a particular need for comprehensive approaches that take into account the specific characteristics of individual locomotive series [6, 7, 10].

The results of the literature review showed that several issues remain unresolved in the field of the wheelset wear assessment and service life prediction. Existing methods often do not fully consider real operating conditions, do not allow for comprehensive analysis of the influence of random factors, and lack the accuracy required for practical application. These shortcomings justify the relevance of developing new, improved methodologies and determine the scientific significance of the proposed research.

III. Materials and Methods

A. Wheelset Wear Analysis

To predict the wheelset wear process and determine their service life, it is necessary to establish analytical relationships for the numerical characteristics of the mean value M_y and the standard deviation based on the set of observed parameters y [11]. Based on statistical data on wheelset wear of TE33A diesel locomotives operated at the Almaty locomotive depot, collected between December 2022 and May 2023, a comparative analysis of the wheelset condition was performed. The results of this analysis are presented in the form of a diagram in Fig. 1.

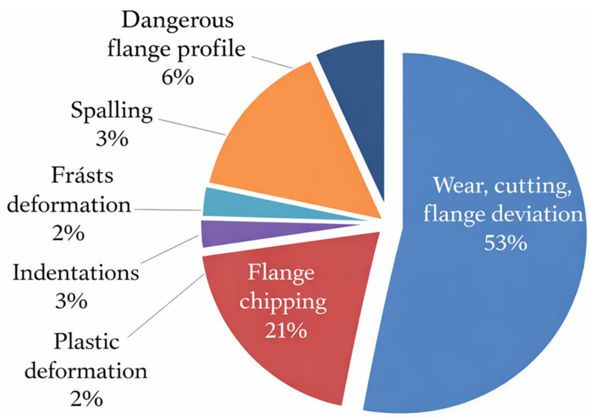


Fig. 1. Classification of wheelset wear types observed in TE33A diesel locomotives during operation.

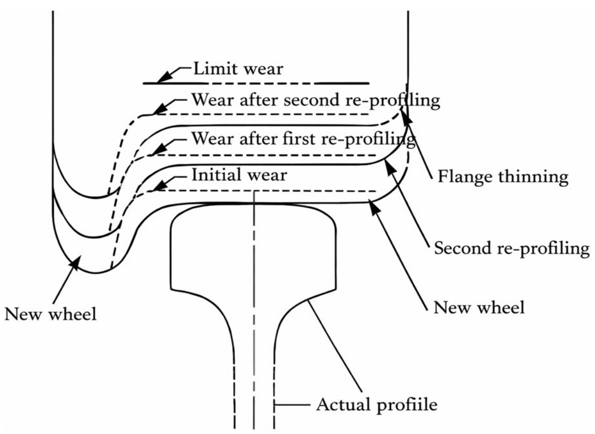


Fig. 2. Schematic illustration of wheel reprofiling according to tread wear progression.

Thinning of the wheelset flange leads to a significant loss of rim material during wheel reprofiling. Therefore, in order to extend wheel service life, the flange thickness should not be reduced to the minimum limits specified by the FRA standards. The disadvantages associated with flange thinning during reprofiling are clearly illustrated in Fig. 2. Compared to normal operational wear, this machining process results in a substantially greater loss of rim material [7, 12].

B. Procedure for Collection and Statistical Processing of Controlled Parameters

The values of monitored parameters are determined during maintenance operations at repair facilities or technical service centers. When the measured parameters exceed the specified permissible limits, component failure occurs. The monitored parameters may either increase or decrease relative to their nominal values; for example, tread wear of the wheel surface increases during operation, whereas the thickness of the wheel flange and wheel tread decreases [13]. The variation of monitored parameters during operation is illustrated in Fig. 3.

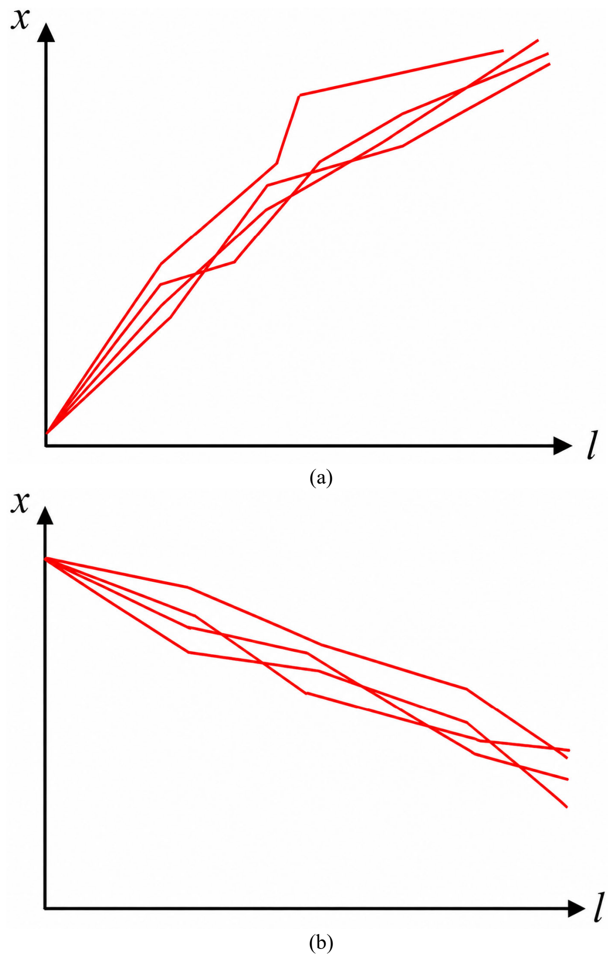


Fig. 3. Variation of monitored parameter values. (a). wheel tread wear; (b). rolling surface thickness.

In this case, the measurement results of the monitored parameters can be considered as equally spaced observational data series. An example of the data aggregation scheme for monitored parameter measurements is presented in Table I.

TABLE I. MEASURED VALUES OF THE MONITORED PARAMETERS OBTAINED DURING MAINTENANCE INSPECTIONS

l	Monitored Parameters					
	1	**2**	**......**	***j***	**.....**	***N***
0	X_{01}	X_{02}	......	X_{0j}	......	X_{0N}
L_1	X_{11}	X_{12}	......	X_{1j}	......	X_{1N}
L_2	X_{21}	X_{22}	......	X_{2j}	......	X_{2N}
......	......	......	......	......	......	......
L_i	X_{i1}	X_{i2}	......	X_{ij}	......	X_{iN}
......	......	......	......	......	......	......
L_n	X_{n1}	X_{n2}	......	X_{nj}	......	X_{nN}

The monitored parameters presented in the table correspond to the parameters of the wheelset under consideration and are recorded in the i-th row of the table. In this study, the monitored parameters include the wheelset flange thickness and wheel tread wear. The data are recorded for successive measurement instances (i = 1,…,n). The number of measurements of a monitored parameter at each observation point (i.e., the number of elements in a given series) may vary or remain constant (N_i), depending on operating conditions. Variations in N_i are primarily caused by unscheduled replacement of components or assemblies. For example, a decrease in N_i for wheelset parameters may result from failures of the wheel-motor unit [4, 14].

The logic of the proposed computational method is structured as an iterative optimization process. To provide a clear understanding of the interaction between statistical data processing and reliability modeling, the algorithmic sequence is presented in Fig. 4. This flowchart demonstrates how the system processes censored operational data to synthesize a unified restoration process, enabling the separation of sudden and gradual failure patterns.

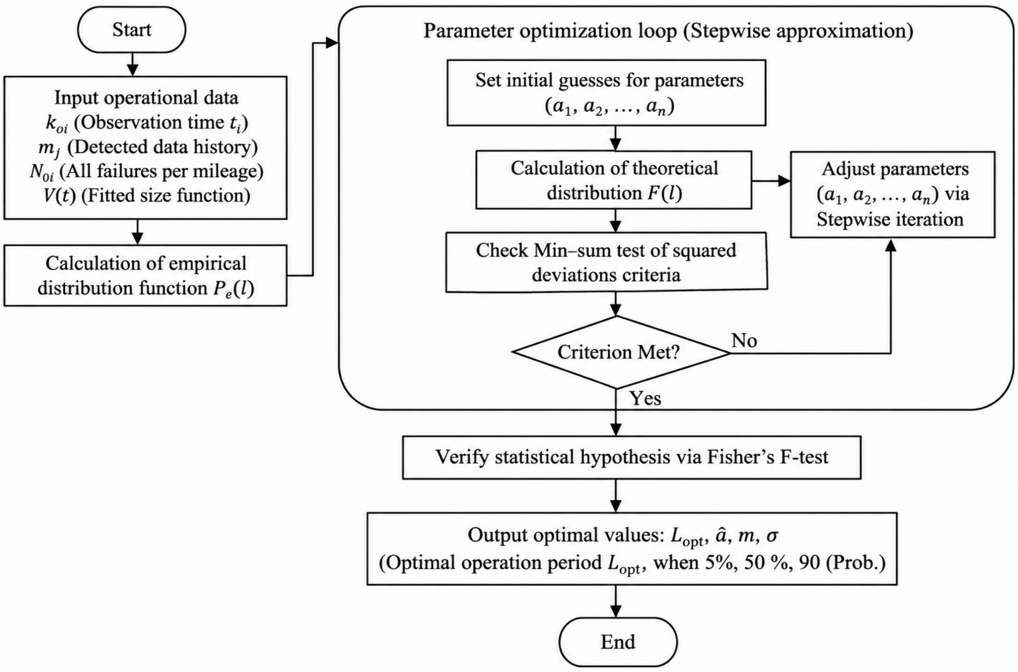


Fig. 4. Flowchart of the proposed computational algorithm for determining the optimal residual life L_{opt} based on the superposition of failure laws and multi-censored operational data.

The measured values of the monitored parameters are treated as random variables until the occurrence of a failure. To ensure the validity of the measurement results, the available data must be represented in the form of a statistical sample. The minimum required sample size, corresponding to the number of measurements of the monitored parameters, is N = 549, as determined based on the specified confidence level and allowable relative error of the statistical estimation.

To estimate the mean:

$$n = \frac{t^2 \times \sigma^2}{\Delta^2} \tag{1}$$

where:
t = 1.96 for 95% confidence;
σ—standard wear deviation;
Δ—marginal error, usually taken as 0.05 or 5%.

To ensure the reliability of the results, the required sample size was determined using statistical power analysis. For a 95% confidence interval and a maximum permissible error of 5%, the minimum required number of observations was calculated to be approximately 380–420 observations. Our actual dataset of N = 549 exceeds this requirement by more than 30%, which guarantees the stability of the statistical estimates and the validity of the resulting reliability indicators.

In practice, continuous monitoring of the parameters is usually not feasible. Measurements are primarily obtained during scheduled maintenance operations or inspections. If the number of measured values of a parameter and the corresponding component are recorded starting from the moment of complete restoration to their nominal condition, a sequence of values obtained from successive measurements represents the realization of the monitored parameter. As the monitored parameter evolves over time, it eventually reaches its specified limit value x_{lim}, at which point component failure occurs [15].

To fully characterize wear processes and service life, a high-frequency dataset is required, including measurements for each locomotive and wheelset.

However, continuous monitoring is not feasible in practice. Therefore, data are mainly collected during maintenance and inspections. If the number of measured values of a monitored parameter and the operating conditions of the corresponding component are clearly defined, a sequence of successive measurements represents the actual evolution of the monitored parameter. When the monitored parameter reaches its specified limit value at a certain point in time, component failure occurs [9, 16].

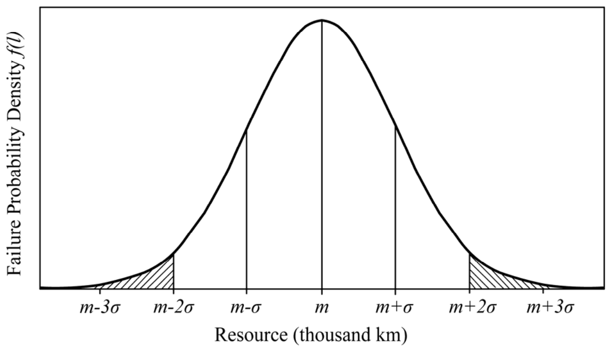


Fig. 5. Theoretical failure density function *f(l)* of the TE33A wheelset resource based on the normal distribution model, illustrating the mean life (m) and standard deviation (σ).

To visualize the adopted reliability model, Fig. 5 presents the theoretical density function of the normal distribution. The mathematical expectation (m) corresponds to the mean mileage to failure, while the standard deviation (σ) captures the variation in wear rates within the fleet. As shown by the shaded percentile areas, 99.73% of all locomotives are predicted to fall within the range of $m = \pm 3\sigma$. This visual representation, in conjunction with Pearson's goodness-of-fit test, clarifies the parametric nature of the wheelset failures used in the residual service life estimation.

Depending on their behavior, monitored parameters can be classified into two types: continuously increasing parameters (e.g., wheel tread wear) and continuously decreasing parameters (e.g., wheel rolling diameter and flange thickness). An example of changes in monitored parameters, including measurements of tread wear and flange thickness, is illustrated in Fig. 6. The statistical data collected during the study were analyzed using methods of mathematical statistics based on Pearson's χ^2 goodness-of-fit test, which evaluates the agreement between empirical (statistical) and theoretical distribution functions. This criterion makes it possible to determine whether the observed differences between the theoretical and empirical distributions do not exceed the variations attributable to random causes.

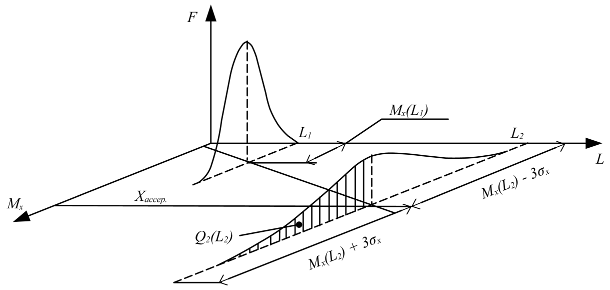


Fig. 6. Time dependence of the system failure probability.

The time dependence of the system failure probability is shown in Fig. 4. The shaded area represents the probability of system failure at time L_2. This probability increases due to a shift in the mean value of the monitored parameter (M_x) and an increase in its (σ_x), as a portion of the distribution curve exceeds the allowable limit. The diagram illustrates how the risk of failure increases over time as a result of component wear [10].

The measurement data obtained for the wheelset were selected and are well described by the normal distribution, which is presented in full below [17]:

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{\frac{(x-m_x)^2}{2\sigma_x^2}} \qquad (2)$$

where:

m_x—statistical estimates of parameters;

σ_x—mean squared deviation of the observed size quantity;

x—current value of the observed size value.

The expression describes the probability that the monitored parameter takes a value x. It characterizes the distribution of data within a large sample, indicating that most values are concentrated near the mean value (μ), while the number of observations decreases as the deviation from the mean increases [18].

For a random variable that follows the normal (Gaussian) distribution, the following relationships apply:

(1) $\sum_{j=1}^{k} P_j^* = 1$—the Integral of the density function of the normal distribution law ($\int f(x)dx$) along the entire number axis is equal to 1;

(2) $\sum_{j=1}^{k} x_j^* = m$—the average of the statistical division is an approximate value for the mathematical care of the theoretical division;

(3) $\sum_{j=1}^{k}\left(x_j - m_x\right)^2 \times P_j^* = D_x$ —statistical variance and is equal to the variance of the theoretical distribution $m_x^* = \frac{1}{N}\sum_{1=j}^{N} x_j$.

$$\sigma_x^* = \sqrt{\frac{1}{N-1}\sum_{j=1}^{N}\left(x_j - m_2^*\right)^2} \qquad (3)$$

The analytical dependence can be represented in the form of certain nonlinear functions $y = f(a_1, a_2, \dots, a_s, l_i)$, where l_i is the independent argument and $a_1, a_2, \dots, a_s, l_i$ are model parameters. Under this formulation, the problem reduces to describing the empirical regression based on a set of N data points (l_i, y_i), where i = 1, 2, … , N. Here, y denotes one of the characteristic measures of the considered distribution. The estimation of the regression parameters is performed using the least squares method, which is presented below [19]:

$$Z(a_1, a_2, \dots, a_s) = \sum_{i=1}^{n}[f(a_1, a_2, \dots, a_s, l_i) - y_i]^2 \Rightarrow min \quad (4)$$

In practice, the empirical dependence of wheelset parameters is well described by linear or polynomial functions. Accordingly, the empirical dependences $m_x^*(l)$ and $\sigma_x^*(l)$ are represented as regression problems. In the simplest case, the describing function can be expressed in linear form as $y = al + b$ are regression coefficients.

To justify the selection of regression model, linear and polynomial approximations were compared using regression quality criteria. Regression analysis results and corresponding model coefficients are presented in Table II.

The analysis showed that the polynomial model provides only a slight increase in approximation accuracy compared to the linear model with increasing complexity of calculations. Additional analyses using the Akaike Information Test (AIC) and the F-test did not reveal a statistically significant advantage of the polynomial model. For further analysis, a linear regression model was chosen, which provides sufficient accuracy, stability and ease of engineering interpretation of the results.

C. *Data Quality Assurance*

To ensure the reliability of the results obtained during data collection and processing, a data quality assurance procedure was implemented.

Geometric measurements of bearing element wear were performed using high-precision measuring instruments with an accuracy of ±0.01 mm. The data were obtained from technical documentation and maintenance logs, and then underwent additional verification before analysis.

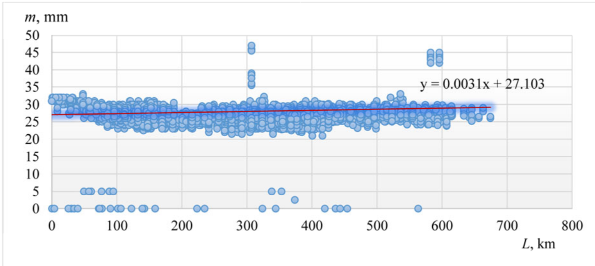
To improve the reliability of the initial dataset, a three-stage data cleaning procedure was used:

- removal of incomplete records;
- exclusion of duplicate measurements;
- detection and removal of emissions beyond the limits of physically permissible operational values.

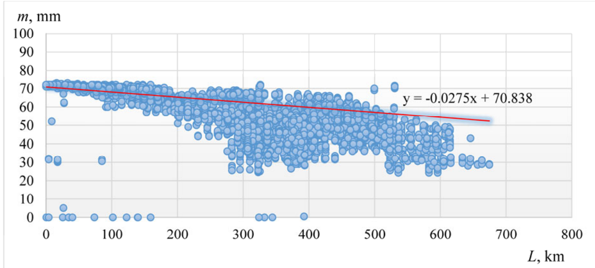
In reduce the effect of random measurement errors, repeated observations were compared, and, where necessary, averaged. Additionally, the scoring algorithm was tested for resistance to abnormal deviations within the dataset.

IV. Results and Discussion

The service life can be predicted based on the numerical characteristics of the probability distribution laws of the monitored parameters by analyzing their evolution with mileage. Specifically, the wheelset service life can be determined from the dependencies $m_x(l)$ and $\sigma_x(l)$ of the measured parameters. Even when extrapolated to the region of high mileage values, these functional dependencies retain their characteristic behavior (Figs. 7 and 8).



(a)



(b)

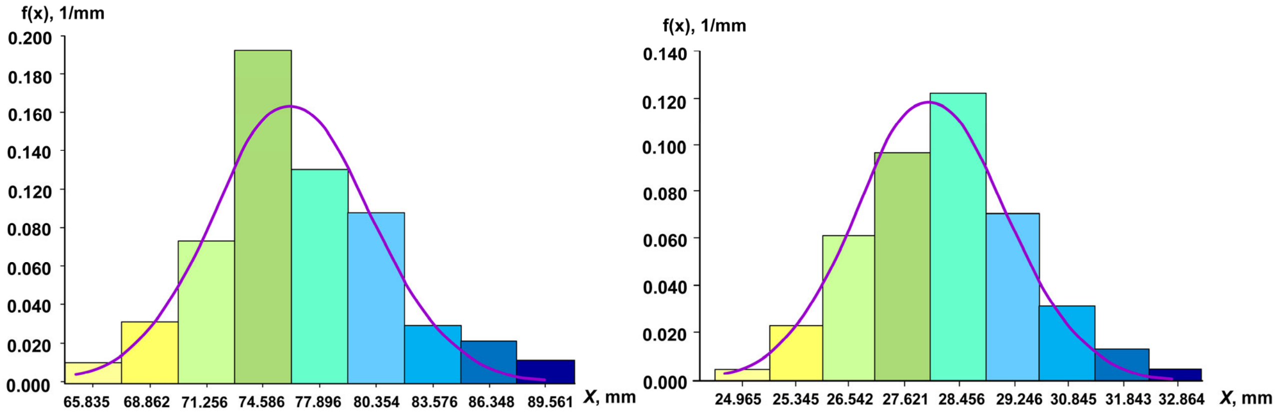
Fig. 7. Dependence of wheel flange and tread deviations on mileage. (a) wheel flange thickness; (b) wheel tread thickness.

Using a known function, the resource distribution function $F(l)$ is determined, and taking into account the specified required percentage of failure-free operation probability γ, the corresponding gamma-percent service life is evaluated for various wheelset configurations.

Based on the quantitative characteristics of the distribution laws of the monitored parameters, it becomes possible to determine the extent of data processing required for service life assessment and to predict their variation trends. In this context, the mean dependence m_x and the mileage-dependent standard deviation σ_x are considered [12, 20].

Regression analysis for the entire fleet (Fig. 8(a)) yielded a near-zero coefficient of determination (R^2). This result is statistically significant and reflects real operating conditions of the TE33A fleet. The extreme dispersion of data points is caused by the restoration processes (wheel turning/re-profiling) performed at the depot.

When a wheelset reaches its wear limit, it is reprofiled to restore the flange. This shifts the data point from the lower boundary (e.g., 24 mm) to the nominal value (e.g., 33 mm) without changing the total mileage. This vertical displacement of data points due to maintenance interventions makes deterministic linear forecasting impossible. Consequently, this justifies the use of a probabilistic reliability model (superposition of laws), which can account for these multi-censored data points where a standard regression fails.



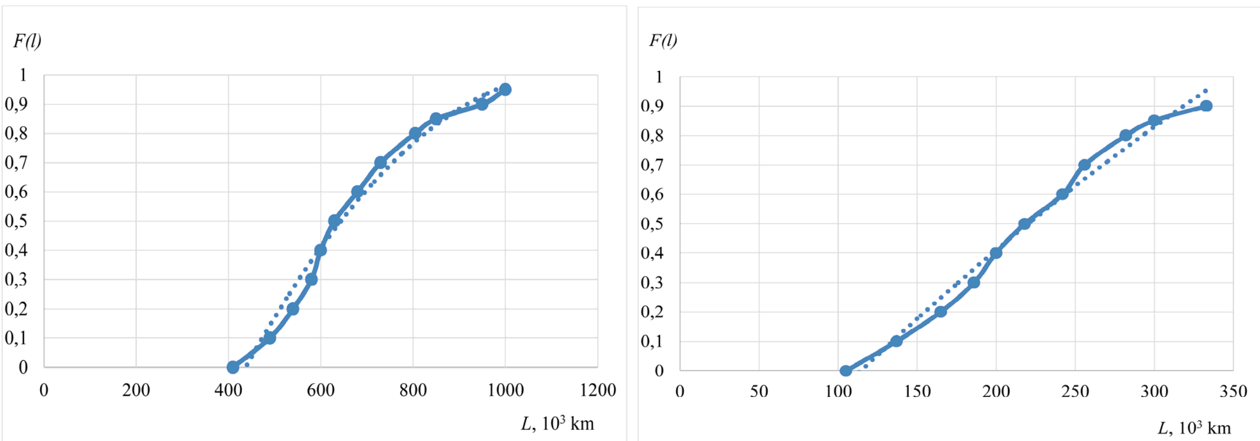
(a) (b)

Fig. 8. Probability distribution function of wheelset tread thick ness. (a) wheel tread thickness; (b) wheel flange thickness.

TABLE II. REGRESSION EQUATION COEFFICIENTS OBTAINED FROM THE REGRESSION ANALYSIS

Calculation Dependence Coefficients		Parameters		
		Wheel Tread Surface	Wheelset Flange Thickness	Wheelset Tread Thickness
$m_x(l)$	a, mm/1000 km	0.0112	–0.0263	–0.0589
	b, mm	0.0831	30.19	89.800
$\sigma_x(l)$	a, mm/1000 km	0.0032	0.0064	0.0101
	b, mm	0.1810	0.5160	1.340

In this study, a mathematical model for evaluating the reliability of wheelsets was developed based on reliability theory. The assessment of durability indicators was carried out using a probability distribution of a random variable with parameters obtained through computer simulation and verified using Pearson's criterion. As a result of the statistical analysis, the average flange wear rate was determined as R = 0.6 mm per 10,000 km, while the average wheelset service life was estimated at 969,574 km. The average service life distribution characteristics of the wheelsets are presented in Fig. 9.



(a) (b)

Fig. 9. Distribution function of the average wheelset service life. (a) wheel tread thickness; (b) wheel flange thickness.

TABLE III. ESTIMATED WEAR INTENSITY AND RELIABILITY-BASED SERVICE LIFE PARAMETERS FOR TE33A WHEELSETS

Parameter	Wear rate, mm/10^4 km	Mean resource, 10^3 km	Gamma-resource (p = 0.9) 10^3 km
Flange thickness	0.263	1085.4	969.5
Tread wear	0.112	1450.2	1280.0
Tread thickness	0.589	1020.8	915.2

Design indicators of wear intensity and reliability service life for TE33A wheelsets are given in Table III.

The final service life estimation was performed in three steps:

(1) Determination of individual wear intensities ai for each parameter using linear regression.

(2) Calculation of the probability of failure-free operation Pl for each parameter based on the normal distribution law.

(3) Identification of the limiting parameter. As shown in Table III, the flange thickness reaches its critical

limit earliest, determining the overall wheelset service life of 969,574 km at a 90% reliability level.

The results of the conducted research repeatedly demonstrate the high relevance of the issue of assessing the wheelset technical condition and predicting their service life for railway transport. The experimental data obtained and the results of their processing showed that the wear processes of wheelsets are complex and multifactorial. This situation justifies the inadequacy of using traditional simple methods for wear assessment and the necessity of employing comprehensive scientific approaches [16, 21].

Measurements of the principle geometric parameters of the wheelsets of the TE33A locomotive during the study showed that their wear rate is directly dependent on operating conditions, load regime, and the quality of maintenance. In particular, the dynamics of tread wear, flange thickness, and rolling diameter were identified as key indicators for assessing the residual service life of wheelsets. Analysis of the time-dependent changes in these parameters allows for an objective assessment of the actual technical condition of the wheelsets.

The application of reliability theory and mathematical statistics within the proposed methodology contributed to increasing the accuracy of the obtained results. By statistically processing operational data, the wear patterns of wheelsets were determined, and the ability to predict their residual service life was ensured. This approach allows for the scientific justification of planned maintenance intervals, the efficient organization of maintenance work, and the prevention of unplanned failures.

The research results showed that random factors have a significant impact on the wear of wheelsets. Factors such as production defects, unstable operating conditions, and uneven loading can lead to significant deviations in the working life of a wheelsets. Therefore, neglecting such factors when predicting service life may lead to inaccurate results. The proposed methodology is distinguished by its ability to account for these random effects.

The analysis identified critical parameters that have the greatest impact on the reliability of wheelsets. By systematically monitoring these parameters, it is possible to predict the probability of wheelset failure in advance. The results obtained allow for optimizing the maintenance system, planning repairs according to actual needs, and using resources efficiently. This, in turn, contributes to reducing locomotive downtime and lowering operating costs.

The practical results of the study demonstrate that application of the proposed methodology reduces unscheduled maintenance and enhances operational safety. Timely detection and replacement of worn wheelsets help prevent accidents. These results are significant both from an economic standpoint and in terms of ensuring railway safety.

Furthermore, the developed methodology possesses sufficient flexibility to be adapted and applied to other types of rolling stock. This expands its potential field of application and creates opportunities for solving various technical problems in the railway transportation industry. However, it should be noted that the effectiveness of the methodology is directly dependent on the quality of the initial measurement data and their systematic collection. Therefore, the future implementation of automated diagnostic systems may further improve the research results.

Overall, the conducted research made it possible to obtain scientifically and practically significant results in the field of wheelset service life assessment and prediction. The conclusions drawn provide a basis for developing specific recommendations aimed at increasing the efficiency of rail vehicle operation, improving the maintenance system, and ensuring operational safety. The research results will support further development of wheelset condition monitoring systems and the implementation of intelligent prediction methods.

V. Conclusion

The obtained results were compared with the technical specifications of the considered locomotive series and with available statistical operational data. The average service life of wheelsets is generally determined by multiple parameters, including the effects of unscheduled maintenance and repairs. However, in the present study, the calculations were performed solely based on wheel tread thickness and flange thickness. Therefore, a complete agreement between the calculated and actual service life values cannot be claimed.

During wheel reprofiling, the nominal values of the monitored parameters, including flange thickness and tread geometry, are restored. In this case, the gamma-percent service life of the wheelset is determined by the minimum value among the monitored parameters. This approach ensures a conservative and reliability-oriented estimation of wheelset service life.

For a more accurate assessment of wheelset durability, it is essential to account for the direct influence of operating conditions on the wear rate of rolling stock components. Accordingly, the mileage between maintenance operations should be adjusted by considering external operational factors affecting wear during service. In future studies, a comprehensive evaluation of wheelset service life should include not only factors influencing the parametric variation of random variables but also an extended set of monitored parameters reflecting real operating conditions throughout the locomotive life cycle.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A.Y. organization and management of research, writing of the manuscript; G.B. experimental work, computer processing and correction of the manuscript, communication with the editorial board of the journal; G.A. assistance with computer processing of the manuscript; T.B. literature review and analysis of methods; G.K. analysis of methods and execution of calculations; all authors had approved the final version; N.J. literature review and analysis of methods; I.A. assistance with computer processing of the manuscript; I.M. assistance with computer processing of the manuscript; all authors had approved the final version.

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