

Application of MTBF Management Tools in Thermal Power Engineering: Analysis of Benefits and Challenges

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Abstract: Growing demands for the reliability and efficiency of power generation assets have made the management of the Mean Time Between Failures (MTBF) indicator a key component of maintenance strategies in thermal power plants. This article presents a structured review of Polish and international literature, with emphasis on publications from 2010 to 2024 and supplemented by foundational works, standards, and industry reports. The review covers methods for measuring, analysing, and improving MTBF, MTTF (Mean Time To Failure), and MTTR (Mean Time To Repair) indicators in the context of thermal power engineering. Based on five detailed case studies from power plants in Poland, Germany, the United Kingdom, and India, documented MTBF increases ranged from 31.7% to 67.4%; in the cases reporting MTTR, reductions ranged from 22.2% to 29.6%. The analysis identifies key implementation barriers, including high investment costs, legacy system constraints, personnel skill gaps, and regulatory requirements. The article also outlines directions for future research on the integration of CMMS systems with IoT platforms and machine learning algorithms.

Keywords: MTBF, thermal power engineering, equipment reliability, CMMS, predictive maintenance, RCM, IEC 60050, thermal power plant

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I. INTRODUCTION

Thermal power engineering plays a fundamental role in the power systems of most European countries. Despite the dynamic development of renewable energy sources, fossil-fuel power plants — burning hard coal, lignite, and natural gas — as well as combined heat and power (CHP) plants and industrial cogeneration facilities continue to provide a significant share of installed capacity, serving a regulatory function in relation to the variability of renewable sources (ARE, 2024). In Poland, according to data from the Energy Market Agency (ARE) for 2023, thermal power plants generated approximately 68% of electricity, making their reliability a matter of strategic importance.

Maintaining continuity of operation in thermal installations is an engineering task of considerable complexity due to extreme operating conditions: high temperatures, working pressures reaching several hundred bars, aggressive chemical environments, and material fatigue phenomena. Industry statistics indicate that unplanned outages at a 500 MW power plant can generate losses of around PLN 0.5-1.5 million per day, accounting for the cost of ungenerated energy, contractual penalties, and restart costs (Dabrowski and Wisniewski, 2022). In this context, precise management of reliability indicators — and particularly the MTBF (Mean Time Between Failures) indicator, in accordance with the terminology of IEC 60050-191 and PN-EN 13306:2018 — takes on significance that is not only technical but also economic.

Traditional approaches to maintenance — reactive (Run-to-Failure) and preventive based on time-based schedules — show significant limitations in the conditions of intensive operation of power installations. Their supplement and successor are data-driven strategies: Reliability-Centered Maintenance (RCM), Predictive Maintenance (PdM), and IT systems for maintenance management (CMMS — Computerized Maintenance Management System) and enterprise asset management (EAM — Enterprise Asset Management). These systems enable the systematic collection, processing, and analysis of failure data, which constitutes the foundation for reliable determination of MTBF, MTTF, and MTTR indicators.

Despite a growing number of industrial implementations, the scientific literature indicates a significant deficit of review-type studies that would comprehensively synthesize the experiences of thermal power plants in the field of MTBF management and assess the benefits of implementations against specific numerical indicator values. The present work fills this gap by setting the following research objectives: (1) systematic presentation of methods for calculating and interpreting MTBF/MTTF/MTTR indicators; (2) a review of IT tools used in thermal power plants; (3) analysis of documented benefits and implementation barriers based on case studies; (4) identification of directions for future research.

The article is directed primarily at maintenance engineers in power plants and researchers working in reliability engineering and physical asset management. The review emphasizes literature published from 2010 to 2024, while also drawing on foundational works, standards, and selected industry reports. Preference was given to publications indexed in the Scopus and Web of Science databases.

II. LITERATURE REVIEW

2.1. Evolution of Reliability Approaches in Power Engineering

The concept of managing the reliability of industrial equipment dates to the 1950s, when the US aviation and defense industries began systematic analysis of military equipment failures. A milestone was the development of the FMEA (Failure Mode and Effects Analysis) methodology by the US Army in 1949 (MIL-P-1629, 1949). In subsequent decades, this methodology was adopted by the nuclear, petrochemical, and energy sectors.

Moubray (1997), in a seminal work from 1997, systematizes the evolution of maintenance strategies, distinguishing three generations: reactive maintenance dominant until the 1950s, preventive maintenance based on schedules (1960s-1980s), and the proactive RCM approach based on reliability analysis (from the 1980s). The RCM approach, described in SAE JA1011, required the development of precise quantitative indicators — including MTBF — as the basis for decision-making.

In the thermal power sector, a breakthrough occurred in the 1990s, when organizations such as the Electric Power Research Institute (EPRI) and VGB PowerTech began systematic collection of equipment failure data. The GADS (Generation Availability Data System) database maintained by the North American Electric Reliability Corporation (NERC) remains to this day one of the most extensive repositories of power plant reliability data (NERC, 2023). In Europe, an analogous function is served by the EUROSTAT database and VGB reports.

Kumamoto and Henley (1996), in a fundamental textbook on probabilistic engineering, note that the MTBF indicator for repairable systems is a function of the failure rate intensity $\lambda(t)$, which in real-world conditions rarely remains constant over time — constituting a significant limitation of the simplified exponential model. Later work by Meeker and Escobar (Meeker and Escobar, 1998) developed the approach based on Weibull distribution analysis as a more realistic description of degradation processes in mechanical equipment.

2.2. CMMS and EAM in Power Plants — State of Research

Campbell and Jardine provide a comprehensive treatment of maintenance management systems, data requirements, and equipment reliability, while empirical studies by Cholasuke et al. (2004) in British industrial facilities highlight the importance of organisational and personnel factors in maintenance management. These observations are particularly relevant to the energy sector, where the technical complexity of equipment demands highly qualified maintenance personnel.

Alsyouf (2007) conducted in 2007 on a sample of 46 Swedish enterprises showed that companies applying advanced maintenance management methods, including CMMS, achieve 9% higher profitability than companies using exclusively reactive maintenance. In the energy sector, similar research was conducted by Tsang (2002), who documents cases of maintenance cost reductions of 10-25% following the implementation of EAM systems.

A systematic review by Shahin et al. (2020) from 2020, covering 78 articles from 2000-2019, identifies as the main barrier to CMMS implementation in the energy sector: lack of standardisation of historical data (indicated by 63% of respondents), difficulties in integration with SCADA and DCS systems (54%), and implementation costs exceeding original budgets (47%).

2.3. Predictive Maintenance and IoT

The integration of CMMS with condition monitoring systems (CMS) and IoT (Internet of Things) platforms has opened new possibilities in terms of MTBF indicator reliability. Lee et al. introduced the concept of the predictive RUL (Remaining Useful Life) indicator, which they treat as a dynamic supplement to the statistical MTBF. Research conducted at a 400 MW gas-steam power plant in Japan showed that a CMS system based on turbine bearing vibration analysis enabled detection of 92% of defects 3-8 weeks before the predicted failure (Tanaka et al., 2021).

A McKinsey & Company (2022) estimates that the integration of predictive maintenance with IoT data analytics can reduce unplanned downtime in power plants by 20-50% and lower maintenance costs by 10-25% (McKinsey & Company, 2022). A limitation of these estimates, however, is their general cross-industry character — the lack of consideration for the specifics of thermal power plants, where sensor density, ambient temperature, and chemical corrosion create conditions that differ from those in manufacturing.

III. METHODOLOGY AND MTBF MANAGEMENT TOOLS

3.1. Definitions and Computational Foundations

In accordance with IEC 60050-191 (International Electrotechnical Vocabulary — Dependability and quality of service), the MTBF (Mean Time Between Failures) indicator is defined as the expected value of time between successive failures of a repairable system or element, expressed by the formula (1):

$$MTBF = \frac{\text{Sum(Operating Time)}}{\text{Number of Failures}} \quad [\text{h}] \quad (1)$$

MTBF must be distinguished from MTTF (Mean Time To Failure), used exclusively for non-repairable elements, defined analogously as the expected value of time to first failure. In the practice of thermal power plants, this applies primarily to single-use elements: rolling bearings, gaskets, and low-level electrical components. The MTTR (Mean Time To Repair) indicator describes the expected value of repair duration, encompassing diagnostic time, waiting time for spare parts, and the time of the actual service intervention (IEC 60050-191:2015, 2015).

For the purposes of the energy sector, the PN-EN 13306:2018 standard (Maintenance — Terminology) and the IEEE Std 762 standard introduce additional operational indicators: EFOR (Equivalent Forced Outage Rate), EFDH (Equivalent Forced Derated Hours), and FOF (Forced Outage Factor). These indicators, combined with MTBF and MTTR, create a comprehensive picture of installation availability, described by the availability indicator (2):

$$A = \frac{MTBF}{(MTBF + MTTR)} \quad (2)$$

In accordance with the general principles of IEC 60300-3-1, MTBF estimation should use historical data that are sufficiently long and representative of the operating conditions being analysed. Shorter observation periods may increase statistical uncertainty and should therefore be interpreted with appropriate caution.

3.2. Weibull Distribution Analysis

The exponential model ($\lambda = \text{constant}$) is a simplification that is rarely fulfilled under real-world conditions. A more general and realistic approach is Weibull distribution analysis, widely applied in reliability engineering for mechanical equipment subject to wear processes. The Weibull distribution is described by the probability density function (3):

$$f(t) = \left(\frac{\beta}{\eta}\right) * \left(\frac{t}{\eta}\right)^{(\beta-1)} * \exp\left[-\left(\frac{t}{\eta}\right)^\beta\right] \quad (3)$$

where: β is the shape parameter ($\beta < 1$: dominance of early-life failures; $\beta = 1$: exponential model; $\beta > 1$: wear); η is the scale parameter (characteristic service life). For steam turbine components, β values typically fall in the range of 1.5-3.5, indicating a dominance of wear mechanisms (Meeker and Escobar, 1998). Estimation of Weibull distribution parameters from historical data is carried out using linear regression on Weibull probability paper or by the Maximum Likelihood Estimation (MLE) method, implemented in specialist software: Relex Reliability Studio, ReliaSoft Weibull++, Windchill Quality Solutions, or the analytical modules of CMMS systems such as SAP PM.

3.3. CMMS and EAM Software — Characteristics

IT systems of the CMMS class integrate work order management, failure history records, inspection planning, and spare parts inventory management. In thermal power plants, both corporate solutions (SAP Plant Maintenance, IBM Maximo, Infor EAM) and specialist solutions (AVEVA Asset Performance Management, OSIsoft PI System integrated with CMMS) are used.

Table 1. Comparison of selected CMMS/EAM systems used in thermal power plants

System	Manufacturer	MTBF Module	IoT Integration	Market Segment
SAP Plant Maintenance (PM)	SAP SE	Yes (PM-EQM)	SAP IoT / HANA	Large corporations
IBM Maximo APM	IBM Corporation	Yes (RCM Workbench)	Watson IoT	Energy, industry
Infor EAM	Infor	Yes (EAM Analytics)	Infor ION	Industry, utilities
AVEVA APM	AVEVA Group	Yes (Reliability)	AVEVA Data Hub	Energy, O&G
eMaint (Fluke)	Fluke Reliability	Partial	Limited	Mid-size facilities
Asseco CMMS	Asseco Poland	Yes	Own platform	Polish market

Source: own elaboration based on (Campbell and Jardine, 2001; SAP SE, 2023; IBM Corporation, 2023).

A key functionality of CMMS systems in the context of MTBF management is the failure event recording module (Failure Reporting, Analysis and Corrective Action System — FRACAS), enabling each failure to be assigned to a specific element, failure mode, and cause codes consistent with ISO 14224 taxonomy. Automatic updating of MTBF indicators occurs upon closure of a work order, enabling ongoing monitoring of reliability trends.

IV. ANALYSIS RESULTS — BENEFITS AND IMPLEMENTATION CHALLENGES

4.1. Case Studies from Thermal Power Plants

4.1.1. Jaworzno III Power Plant, Poland

Jaworzno III Power Plant (installed capacity: 1,345 MW), managed by TAURON Wytwarzanie S.A., carried out the implementation of an SAP PM system integrated with the existing Siemens SPPA-T3000 DCS system during 2014-2016. Prior to CMMS implementation, the average MTBF indicator for critical boiler feed pumps was 2,840 hours, and the MTTR indicator was 36 hours. After two years of system operation and standardisation of FRACAS procedures, the MTBF indicator rose to 4,210 hours (+48.2%), with simultaneous reduction of MTTR to 28 hours (-22.2%), corresponding to an increase in availability from 98.74% to 99.34% (Kowalczyk and Baran, 2017). The key success factor was the integration of the failure history database with the SAP PM Weibull analysis module, enabling automatic generation of inspection interval recommendations for each technical asset.

4.1.2. Kraftwerk Lippendorf, Germany

Lippendorf Power Plant (capacity: 2 x 934 MW, lignite), operated by LEAG GmbH, implemented the AVEVA APM platform in 2017, integrated with the OSIsoft PI system for real-time monitoring of 12,400 measurement points. Keil et al. (2020) document that following system implementation (2017-2019), the average MTBF indicator for steam turbines increased from 6,120 h to 8,890 h (+45.3%), and the number of unplanned failures decreased from 23 to 11 events per year (-52.2%). Predictive vibration analysis of turbogenerator bearings proved particularly significant, enabling planned intervention without stopping the unit in 7 of 11 cases — through bearing replacement during planned maintenance windows. The authors estimate net savings in the first three years at approximately EUR 4.7 million.

4.1.3. Drax Power Station, United Kingdom

Drax Power Station (Yorkshire, original capacity: 3,906 MW), in the process of conversion to biomass, implemented the IBM Maximo APM system during 2018-2020. Smith and Morgan analyse data from biomass units 1-4 and document an increase in MTBF for biomass mills from 1,380 h to 2,310 h (+67.4%) within 24 months of full system functionality launch. This improvement resulted primarily from the implementation of an RCM strategy based on the failure history recorded in the Maximo system, which enabled identification of the dominant failure mode — abrasive wear of milling discs — and optimisation of their replacement schedule from 2,000 h to 1,600 h. The MTTR indicator was reduced from 18 h to 11 h through improvements to the spare parts warehouse logistics procedures.

4.1.4. NTPC Vindhyachal Super Thermal Power Station, India

NTPC Vindhyachal Power Station (capacity: 4,760 MW, hard coal) is one of the largest energy facilities in Asia. Sharma and Kumar describe the implementation of IBM Maximo during 2015-2017 as part of NTPC's maintenance management modernisation programme. Prior to CMMS implementation, the average MTBF indicator for steam boilers was 3,240 h, with an MTTR of 54 h. Following standardisation of failure recording procedures and implementation of the RCM Workbench module, the MTBF indicator increased to 4,720 h (+45.7%), and MTTR was reduced to 38 h (-29.6%). The authors emphasise the particular value of automatic generation of preventive maintenance work orders (PM Orders) based on determined optimal service intervals.

4.1.5. EC Krakow (Combined Heat and Power Plant), Poland

Elektrociepłownia Krakow S.A. (thermal capacity: 1,165 MW, electrical: 442 MW) implemented the Infor EAM system in 2019, integrated with the Siemens MindSphere IoT platform. Within the pilot project, monitoring covered a group of circulation pumps and fans — 84 technical assets in total. Wilk and Nowak (2021) document that in the first year after implementation, the number of unplanned pump stoppages decreased by 31%, and the MTBF indicator rose from 2,180 h to 2,870 h (+31.7%). The cost was a lengthy project launch period (14 months versus the planned 9) resulting from difficulties in integrating the EAM system with the existing ABB SCADA infrastructure.

Table 2. Summary of CMMS/EAM implementation results in thermal power plants — case study overview

Facility	System	Component	MTBF Before (h)	MTBF After (h)	Change (%)	MTTR Before (h)	MTTR After (h)
Jaworzno III, PL	SAP PM	Feedpumps	2,840	4,210	+48.2%	36	28
Lippendorf, DE	AVEVA APM	Steamturbines	6,120	8,890	+45.3%	n/a	n/a
Drax, UK	IBM Maximo	Biomassmills	1,380	2,310	+67.4%	18	11
Vindhyachal, IN	IBM Maximo	Steamboilers	3,240	4,720	+45.7%	54	38
EC Krakow, PL	Infor EAM + IoT	Circulationpumps	2,180	2,870	+31.7%	n/a	n/a

Source: own elaboration based on (Kowalczyk and Baran, 2017; Keil et al., 2020; Smith and Morgan, 2021; Sharma and Kumar, 2020; Wilk and Nowak, 2021). n/a — data not available.

4.2. Benefits of Implementing MTBF Management Tools

Analysis of the cited case studies and literature review (MIL-P-1629, 1949; Moubray, 1997; NERC, 2023; Kumamoto and Henley, 1996; Meeker and Escobar, 1998; Campbell and Jardine, 2001; Cholasuke et al., 2004; Alsyoud, 2007; Tsang, 2002; Shahin et al., 2020; Lee et al., 2015; Tanaka et al., 2021; McKinsey & Company, 2022; IEC 60050-191:2015, 2015; SAP SE, 2023; IBM Corporation, 2023; Kowalczyk and Baran, 2017; Keil et al., 2020; Smith and Morgan, 2021; Sharma and Kumar, 2020; Wilk and Nowak, 2021) enables identification of the following benefit categories:

1. Improvement of reliability indicators: the increase in MTBF values in the analysed cases ranged from 31.7% (EC Krakow) to 67.4% (Drax), with a median of approximately 45.7%. These findings are consistent with the broader maintenance-management literature discussed by Tsang (2002), although the case-study evidence remains limited in size and scope.
2. Reduction of maintenance costs: systematic tracking of failure history and optimisation of service intervals enable the elimination of redundant preventive inspections. EPRI estimates (NERC, 2023) indicate possible maintenance cost reductions of 10-30% within 3-5 years of implementation.
3. Increased installation availability: reduction of MTTR by 22-30% (observed at Jaworzno III and Vindhyachal) directly translates into an increase in the availability indicator A. For a 500 MW power plant, an improvement in availability of 0.5 percentage points can mean an additional 21,900 MWh annually.
4. Standardisation of engineering knowledge: failure databases constitute a resource of institutional knowledge, independent of personnel turnover. This issue is particularly relevant in the context of the mass departures of experienced engineers from the energy sector in Poland, forecast through to 2030 (PTEZ, 2023).
5. Support for investment decisions: CMMS data enables reliable modelling of equipment life cycles (LCC — Life Cycle Cost), which is essential for justifying decisions on capital overhaul or replacement of generating units.

4.3. Implementation Barriers and Challenges

Despite the documented benefits, implementation of MTBF management systems encounters several significant barriers, consistently identified in the literature and confirmed in survey studies.

4.3.1. Investment Costs and Long Payback Periods

Implementing a corporate-class CMMS system in a thermal power plant involves costs in the range of PLN 2-15 million (depending on the number of technical assets, degree of integration, and scope of historical data migration). Survey studies conducted by Plant Engineering (2023) on a sample of 307 industrial facilities showed that 41% of implementations exceed the original budget, and the median return on investment (ROI) period is 3.2 years (Plant Engineering, 2023). For privatised power plants operating under price pressure in the wholesale energy market, this horizon may be unacceptable from a short-term financial perspective.

4.3.2. Legacy Systems and Infrastructure Heterogeneity

Polish thermal power plants operate installations of varying technological ages: alongside modern supercritical units (post-2010), plants dating from the 1970s still operate in the system. Integrating data from DCS systems of different generations (Siemens, ABB, Emerson, Metso) with a CMMS platform requires a dedicated middleware layer or OPC-UA, generating additional costs and cyber-physical security risks. This issue is analysed more broadly by Hollingsworth et al. (2022) in the context of industrial control systems.

4.3.3. Quality and Completeness of Historical Data

The reliability of the MTBF indicator is directly proportional to the completeness and quality of failure event data. A review of 12 Polish power plants conducted by the InstytutEnergetyki (2021) showed that only 34% of them maintained full digital failure documentation, 47% used paper failure registers, and 19% did not maintain systematic failure records (InstytutEnergetyki, 2021). Migration of historical data to a CMMS system is a laborious process requiring unification of nomenclature and failure mode coding in accordance with ISO 14224 taxonomy.

4.3.4. Personnel Skills Deficit

Effective MTBF management requires technical personnel to possess competencies in statistics and reliability engineering, which have traditionally not formed part of engineering education programmes for power engineers. Analysis of job postings in the energy sector in Poland (Pracuj.pl portal, 2023-2024) shows that only 12% of advertisements for maintenance specialists require knowledge of reliability analysis methods (Pracuj.pl, 2023–2024). This deficit is a limiting factor for both the quality of data collected and the capacity to interpret and use MTBF indicators in decision-making processes.

4.3.5. Regulatory Requirements of the EU Energy Sector

Directive (EU) 2019/944 establishes common rules for the internal electricity market, while REMIT provides the EU framework for wholesale energy market integrity and transparency. In this regulatory environment, reliable operational data are increasingly important for internal asset management and for processes connected with market and system reporting. CMMS systems can support the preparation and traceability of such data, although the exact reporting requirements and interfaces depend on the applicable national and market rules (European Parliament and Council of the European Union, 2011, 2019; Energy Regulatory Office (URE), 2023).

V. DISCUSSION

The collected evidence indicates that implementing MTBF management systems in thermal power plants can produce measurable reliability benefits; however, the scale of improvement is strongly differentiated depending on the specifics of the facility, scope of implementation, and maturity of organisational processes. Analysis of five case studies indicates MTBF increases of 31.7-67.4%. The upper end of this range (Drax, +67.4%) should be interpreted cautiously because the available case-study evidence is limited and the baseline conditions differed between facilities.

An interesting observation is the greater effectiveness of implementations conducted simultaneously with an organizational transformation programme for maintenance (Jaworzno III, Vindhychal) compared to purely technological implementations. This result is consistent with observations by Campbell and Reyes-Picknell, indicating the dominant role of process and competency factors in determining CMMS success.

A separate issue is the comparability of data between facilities. The absence of a unified standard for reporting MTBF results (beyond the general guidance of ISO 14224) makes it difficult to compare results from different power plants and limits the possibility of building industry benchmarks. VGB PowerTech made an attempt at standardisation through the KISSY (Kraftwerk-Informationssystem) database, but this database remains available only to members of the organisation and is not publicly accessible for academic verification.

Integration of CMMS with IoT platforms and machine learning systems represents a promising development direction; however, the results of available research are thus far more optimistic in their forecasts than in their documented outcomes. The EC Krakow case (+31.7% MTBF with IoT integration) is one of the first documented implementations in the Polish energy sector, but the limited number of monitored assets (84) and short observation horizon (12 months) do not allow for generalisation of conclusions.

European regulations (Directive 2019/944, REMIT regulation) create institutional frameworks conducive to the digitalisation of maintenance management, while simultaneously raising quality requirements. Energy companies in Poland and the EU should treat MTBF management systems not only as a tool for operational optimisation, but as a component of regulatory compliance.

VI. LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

The present article is subject to several limitations that should be taken into account when interpreting its results. Firstly, the selection of case studies was not random — the analysed cases cover facilities in which implementations were successful and were documented in the literature, which may lead to publication bias and overestimation of typical implementation benefits. Power plants in which implementations failed or did not produce the expected results rarely become the subject of scientific publications.

Secondly, the comparability of results between facilities is limited due to different operational definitions of MTBF used by individual authors and companies. Some publications define MTBF exclusively

for failures leading to unit stoppage (Forced Outage), while others include all maintenance events, leading to numerically incomparable results.

Thirdly, the observation horizon in the analysed case studies is varied (1-3 years) and may not be sufficient to capture the long-term effects of implementation, including the regression to the mean effect following initial implementation enthusiasm.

Based on the identified limitations, the following directions for future research are proposed: (1) conducting long-term (5+ years) cohort studies comparing power plants with and without CMMS implementation, using a unified MTBF definition; (2) development of a standard protocol for reporting CMMS implementation results in the energy sector, analogous to CONSORT criteria in medical sciences; (3) research into the effectiveness of machine learning algorithms (LSTM, Random Forest) in predicting MTBF for specific equipment classes in thermal power plants; (4) econometric analysis of the impact of maintenance management process maturity (measured by the MRL — Maintenance Readiness Level scale) on achieved MTBF values; (5) research into factors affecting the quality of historical data in CMMS systems, with particular focus on aspects of system ergonomics and operator motivation to reliably report failures.

VII. CONCLUSIONS

Based on the conducted literature review and analysis of five case studies from thermal power plants in Poland, Germany, the United Kingdom, and India, the following final conclusions are formulated:

1. The analysed case studies document MTBF increases in the range of 31.7-67.4%, with a median of approximately 45.7%. These results are consistent with the broader maintenance-management literature, but the limited number and non-random selection of cases do not justify treating the observed range as a universal effect.
2. A key condition for implementation effectiveness is the completeness and quality of historical failure data, collected in a format compliant with ISO 14224. CMMS technology constitutes a necessary but insufficient tool — without a change in organisational culture and reporting procedures, its potential is significantly limited.
3. The main implementation barriers are: high investment costs and long payback periods (median ROI: 3.2 years), heterogeneity of legacy system infrastructure, deficits in analytical competencies of technical personnel, and regulatory requirements. These barriers are complex in nature and require a coordinated technical-organisational approach.
4. Integration of CMMS systems with IoT platforms and predictive algorithms represents a promising direction, enabling the transition from a statistical (retrospective) MTBF model to dynamic, predictive RUL indicators. The first documented implementations in thermal power plants (EC Krakow, Lippendorf) yield positive results, but the literature in this area remains in the process of development.
5. Directive (EU) 2019/944 and the REMIT framework form part of the regulatory context in which electricity-market participants operate. Reliable maintenance and operational data can support digitalised asset-management processes and improve the traceability of information used in operational and reporting activities.

CONFLICT OF INTEREST

The author declares no conflict of interest.

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