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STRATEGIC PROJECT MANAGEMENT IN THE ORGANIZATION OF INDUSTRIAL MAINTENANCE SYSTEMS

Review paper

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Abstract: Industry 4.0 technologies, including predictive analytics, artificial intelligence, and data-driven monitoring solutions, have significantly influenced the digital transformation of industrial maintenance systems. While these approaches improve operational efficiency and reliability, they often lack structured integration within broader organizational and strategic management frameworks. The emerging Industry 5.0 paradigm introduces a human-centric, resilient, and sustainable perspective, requiring a transition from technology-oriented maintenance models toward strategically coordinated systems.
This paper examines the transition from Industry 4.0 to Industry 5.0 within industrial maintenance organizations, with emphasis on the integration of strategic project management into digital maintenance initiatives. The review addresses three research questions concerning the integration of strategic project management into digital maintenance systems, organizational factors affecting the implementation of predictive maintenance, and the Industry 5.0 principles relevant to maintenance project management. Based on a structured review of recent literature, the study identifies a research gap concerning the alignment of predictive maintenance initiatives with strategic planning, organizational restructuring, and long-term business performance objectives.
A conceptual framework is proposed that integrates digital maintenance technologies, strategic project management, and human-centric Industry 5.0 principles. The framework distinguishes strategic project management as an integration layer that connects technological implementation with organizational objectives, resource allocation, risk management, stakeholder engagement, and performance monitoring. The paper contributes a structured perspective for coordinating digital maintenance initiatives with organizational and human factors and provides a basis for future empirical research and practical application in industrial maintenance systems.
Key words: Industry 4.0, Industry 5.0, strategic project management, industrial maintenance systems, digital transformation, human-centric management

INTRODUCTION

The rapid evolution of digital technologies has significantly transformed industrial production and maintenance systems over the past decade. Industry 4.0 has influenced maintenance practices, shifting them from reactive and preventive models toward predictive and condition-based strategies based on artificial intelligence, machine learning, and real-time data analytics (Taoufyq et al., 2025; Mallioris, 2024). These advancements have enabled organizations to reduce downtime, improve spare parts management, and improve equipment reliability.
However, despite technological progress, many industrial maintenance systems remain fragmented, lacking structured integration with strategic management and long-term business planning processes. Recent studies emphasize that predictive maintenance models frequently focus on algorithmic accuracy and technical performance, while organizational alignment and project governance structures are often neglected (Carvalho et al., 2021; Softić, 2024). In practice, this results in digital initiatives being implemented as isolated technical upgrades rather than as strategically managed transformation programs. Consequently, the expected improvements in operational efficiency and financial performance are not always fully realized.
The emerging Industry 5.0 paradigm introduces a broader perspective, highlighting human-centricity, resilience, and sustainability as key dimensions of industrial development (Benhanifia et al., 2025; Ramzan & Reforgiato, 2025). Unlike Industry 4.0, which is primarily technology-driven, Industry 5.0 promotes the integration of advanced technologies with human expertise, collaborative decision-making, and socially responsible management practices. For

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industrial maintenance systems, this shift implies the need for coordinated organizational restructuring, workforce adaptation, and risk-aware planning mechanisms.

Several authors underline that digital transformation in maintenance environments requires not only advanced analytical tools but also structured governance frameworks capable of aligning technological innovation with strategic objectives (Rios et al., 2024; Achouch et al., 2022). The transition from Industry 4.0 to Industry 5.0 therefore cannot be achieved solely through technological upgrades; it demands the application of strategic project management principles to support systematic planning, stakeholder engagement, resource allocation, and performance monitoring.

Despite growing interest in Industry 5.0 concepts, there remains a limited number of studies that explicitly address the integration of predictive maintenance systems with strategic project management at the organizational level (Ali, 2024; Murtaza et al., 2024). This gap is particularly evident in industrial environments where maintenance systems represent significant assets influencing production continuity, cost efficiency, and competitive positioning.

To address this research gap, the study examines the relationship between digital maintenance technologies, strategic project management, and human-centric Industry 5.0 principles. Three research questions guide the analysis:

RQ1: How is strategic project management integrated into digital industrial maintenance systems?

RQ2: What organizational factors and barriers affect the implementation of predictive maintenance within industrial maintenance systems?

RQ3: Which Industry 5.0 principles are relevant to strategic project management of industrial maintenance initiatives?

The objective of this paper is to analyze the transition from Industry 4.0 to Industry 5.0 in industrial maintenance systems and to propose a conceptual framework that integrates digital maintenance technologies with strategic project management principles. The framework aims to support human-centric implementation, improve organizational resilience, and align maintenance activities with long-term business performance goals.

LITERATURE REVIEW

The development of industrial maintenance systems has been extensively studied in the context of predictive maintenance, machine learning applications, and digital transformation initiatives (Taoufyq et al., 2025; Mallioris, 2024; Carvalho et al., 2021). Taoufyq et al. (2025) provide a systematic evaluation of knowledge-based, physics-based, and data-driven predictive maintenance models, highlighting the need for empirical validation across industries and integration with structured project management frameworks. Similarly, Mallioris (2024) reviews state-of-the-art predictive maintenance applications across multiple sectors, pointing out insufficient integration with practical project management and organizational maintenance frameworks.

Other studies emphasize technological approaches without sufficient organizational perspective. Carvalho et al. (2021) focus on machine learning techniques applied to predictive maintenance, but the alignment with strategic project management remains underexplored. Softić (2024) demonstrates the application of survival analysis for reliability assessment; however, these methodologies have not been fully integrated into organizational maintenance systems.

The reviewed literature can be considered through three related perspectives. The first concerns the technological dimension of predictive maintenance, including machine learning, artificial intelligence, data-driven models, condition monitoring, and Industry 4.0 technologies (Taoufyq et al., 2025; Carvalho et al., 2021; Achouch et al., 2022; Benhanifia et al., 2025). These studies demonstrate the development of increasingly advanced approaches for monitoring equipment condition, predicting failures, and supporting maintenance decisions. However, the main emphasis is generally placed on technical models and their application rather than on the organizational management of their implementation.

The second perspective concerns maintenance planning and organizational integration. Rios et al. (2024) examine machine learning applications for maintenance planning and asset integrity management, while Ali (2024) discusses maintenance strategies from a broader management perspective. Bokrantz et al. (2020) and Emroozi et al. (2023) also address the integration of maintenance activities with wider production and organizational processes. These studies indicate the importance of coordinated maintenance planning, but the connection between maintenance initiatives and strategic project management remains insufficiently developed.

The third perspective is related to the transition toward human-centric Industry 5.0 maintenance systems. Ramzan and Reforgiato (2025) consider predictive maintenance in smart manufacturing with emphasis on artificial intelligence and decision-making, while Murtaza et al. (2024) examine the transition from Industry 4.0 toward Industry 5.0 and the increasing relevance of human-centric approaches. Benhanifia et al. (2025) also address predictive maintenance practices based on AI and IoT technologies. Although these studies introduce organizational and human-oriented considerations, the integration of Industry 5.0 principles with strategic project management for maintenance initiatives remains insufficiently defined.

To consolidate recent findings and identify gaps in current research, a structured overview of key studies from 2020 to 2026 is presented in Table 1. The table summarizes the main focus, limitations, and research gaps identified in the selected literature, with particular attention to predictive maintenance, industrial maintenance management, and project management.

Table 1. *Overview of Recent Literature on Predictive Maintenance, Industrial Maintenance Management, and Project Management (2020–2026)*

Author (Year)	Title	Focus	Limitation	Research Gap
Taoufyq, H. et al. (2025)	Predictive Maintenance Approaches A Systematic Literature Review	Systematic evaluation of knowledge-based, physics-based and data-driven predictive maintenance models	Limited real-world industrial validation	Need for empirical validation across industries and integration with structured project management frameworks
Mallioris, P. (2024)	Predictive Maintenance in Industry 4.0 A Systematic Multi-Sector Review	State-of-the-art predictive maintenance applications across multiple industries	Systematic review without in-depth industrial case studies	Insufficient integration with practical project management and organizational maintenance frameworks
Carvalho, T. P. et al. (2021)	A Systematic Literature Review of Machine Learning Methods Applied to Predictive Maintenance	Machine learning techniques applied to predictive maintenance	Strong technological orientation	Lack of organizational and strategic project management perspective
Softić, S. (2024)	Case Studies of Survival	Application of survival analysis	Methodological focus without	Need for application of

	Analysis for Predictive Maintenance	models for reliability assessment	integration into maintenance organization systems	survival models in strategic maintenance planning and project-based environments
Benhanifia, A. et al. (2025)	Systematic Review of Predictive Maintenance Practices in the Manufacturing Sector	Implementation of predictive maintenance using AI and IoT technologies	Predominantly technology-driven analysis	Limited connection between predictive maintenance and strategic maintenance project management
Ramzan, F. and Reforgiato, D. (2025)	A Literature Review on Enhancing Predictive Maintenance in Smart Manufacturing Industries	Comprehensive survey of AI-driven predictive maintenance and decision-making challenges	Focused on AI and data architecture	Gap in structured project management models and human-technology coordination frameworks
Rios, M. P. et al. (2024)	Optimising Maintenance Planning and Integrity in Offshore Facilities Using Machine Learning	Machine learning models for maintenance planning and asset integrity management	Sector-specific focus on offshore facilities	Need for broader industrial application within formal project management structures
Achouch, M. et al. (2022)	On Predictive Maintenance in Industry 4.0 Overview Models and Challenges	Overview of predictive maintenance models and workflows in Industry 4.0	Primarily technical and model-oriented	Lack of integration with strategic and business-oriented project management frameworks
Ali, S. (2024)	Review Optimizing Maintenance Management in Modern Industrial Facilities	Strategies for improving maintenance management performance	General management perspective without project management integration	Need for structured project-based implementation models in maintenance systems
Murtaza, A. et al. (2024)	Paradigm Shift for Predictive Maintenance and Condition Monitoring from Industry 4.0 to Industry 5.0 A Systematic	Human-centric and Industry 5.0 oriented predictive maintenance models	Conceptual and review-based orientation	Gap in project-centric execution models for predictive maintenance implementation

	Review Challenges and Case Study			
Bokrantz, J. et al. (2020)	Smart Maintenance: a research agenda for industrial maintenance management	Conceptualization of smart maintenance and future research agenda	Theoretical framework without empirical validation	Need for implementation models aligned with strategic project management and business performance objectives
Emroozi, V. B. et al. (2023)	Improving industrial maintenance efficiency a holistic approach to integrated production and maintenance planning with human error optimization	Development of integrated production and maintenance planning that incorporates human error optimization to improve overall industrial maintenance efficiency	Model-based study with simulation/analytical validation	Need for integration with strategic project management frameworks and wider empirical validation across multiple industrial contexts

The reviewed studies show that predictive maintenance research has developed substantially in terms of digital technologies, analytical models, and condition monitoring approaches. At the same time, the organizational aspects of implementing these technologies are less consistently addressed. The literature also indicates a growing interest in human-centric maintenance and Industry 5.0 principles, particularly in relation to workforce involvement, decision-making, resilience, and coordination between technological and human factors.

A further gap concerns the connection between these dimensions and strategic project management. Existing studies address predictive maintenance technologies, maintenance planning, organizational integration, and Industry 5.0 principles, but these elements are generally examined separately. The reviewed literature provides limited guidance on how strategic project management can connect technological implementation with organizational objectives, resource allocation, risk management, stakeholder engagement, and performance monitoring.

This gap provides the basis for the conceptual framework developed in this study. The proposed framework does not introduce predictive maintenance or Industry 5.0 principles as new concepts; instead, it focuses on their structured integration through strategic project management. In this perspective, strategic project management represents the connecting layer between digital maintenance technologies, organizational objectives, and human-centric Industry 5.0 requirements.

METHODOLOGICAL RESEARCH APPROACH

This study adopts a systematic literature review (SLR) approach to analyze recent research on predictive maintenance, industrial maintenance management, and strategic project management, covering publications from 2020 to 2026. The review was structured around the relationship between digital maintenance technologies, organizational management practices, and the principles of Industry 5.0.

The literature search focused on three major academic databases, Scopus, Web of Science, and Google Scholar. The search used combinations of the following keywords and related

terms: "predictive maintenance", "Industry 4.0", "Industry 5.0", "strategic project management", "industrial maintenance systems", and "human-centric maintenance". The search was limited to publications written in English and published between 2020 and 2026.

The inclusion criteria focused on peer-reviewed journal articles and high-quality research papers addressing at least one of the following areas: predictive maintenance, digital transformation of industrial maintenance, maintenance management, Industry 4.0 or Industry 5.0 applications in maintenance, or the organizational and management aspects of maintenance implementation. Studies were considered relevant when their findings provided insights applicable to the relationship between predictive maintenance, organizational management, and strategic project management.

Studies focused exclusively on technical algorithms or specific predictive maintenance models were not excluded when their findings provided relevant implications for the organizational implementation, planning, or management of maintenance systems. Publications without a relevant connection to industrial maintenance, digital maintenance technologies, organizational implementation, or the Industry 4.0 and Industry 5.0 context were not considered relevant to the research focus.

The screening process was based on the relevance of the publication to the research topic and the extent to which the reported findings could contribute to understanding the integration of digital maintenance technologies with organizational and strategic management practices. Particular attention was given to studies addressing implementation challenges, organizational requirements, human factors, maintenance planning, and project-oriented approaches.

The selected studies were analyzed according to their authors, publication year, research focus, methodological or practical limitations, and identified research gaps. These characteristics were summarized in Table 1. The analysis was used to identify recurring themes and areas in which existing research provides limited guidance, particularly regarding the integration of predictive maintenance with strategic project management.

The synthesis of the reviewed literature was structured around three interconnected dimensions. The first dimension concerns Industry 4.0 technologies and digital maintenance, including predictive maintenance, machine learning, condition monitoring, and real-time data analysis. The second dimension concerns strategic project management and its relevance to maintenance planning, resource allocation, risk management, stakeholder engagement, and performance monitoring. The third dimension concerns Industry 5.0 principles, including human-centricity, resilience, sustainability, workforce participation, and the coordination of human expertise with digital technologies.

The identified relationships between these dimensions were used as the basis for developing the conceptual framework presented in the following section. The framework connects digital maintenance technologies with strategic project management and human-centric Industry 5.0 principles, with the aim of providing a structured perspective for the implementation and management of industrial maintenance initiatives.

CONCEPTUAL FRAMEWORK / PROPOSED MODEL

The proposed conceptual framework integrates digital maintenance technologies, strategic project management, and human-centric Industry 5.0 principles into a coordinated model for industrial maintenance systems. The framework is structured around four interconnected elements: the Industry 4.0 Digital Maintenance Layer, the Strategic Project Management Layer, the Human-Centric Industry 5.0 Layer, and the Integration Mechanism. The model is intended to connect technological implementation with organizational objectives, project management practices, and human factors.

Industry 4.0 Digital Maintenance Layer

The first layer represents the technological foundation of the proposed framework. It includes predictive maintenance, machine learning, survival analysis, condition monitoring, and real-time data acquisition and analytics. These technologies provide information about equipment

condition and support maintenance decision-making based on operational data. However, technological solutions implemented as isolated tools may have limited organizational value when they are not connected with maintenance planning, resource allocation, and broader business objectives.

Strategic Project Management Layer

The second layer introduces strategic project management as a distinct organizational component of the framework. Its purpose is to align digital maintenance initiatives with organizational objectives through structured planning, resource allocation, risk management, stakeholder engagement, and performance monitoring. Maintenance digitalization is therefore considered as a managed organizational initiative rather than only a technological implementation. This layer also provides a basis for coordinating activities between maintenance, production, management, information technology, and other relevant organizational functions.

Human-Centric Industry 5.0 Layer

The third layer incorporates the human-centric principles associated with Industry 5.0. It includes workforce participation, human expertise, ergonomics, continuous learning, resilience, sustainability, and socially responsible practices. The implementation of digital maintenance technologies requires consideration of employee competencies and the interaction between workers and technological systems. Human expertise remains relevant for interpreting maintenance information, making operational decisions, and adapting maintenance practices to specific organizational conditions.

Integration Mechanism

The integration mechanism connects the three main dimensions of the framework. It links digital maintenance technologies with strategic project management and human-centric organizational requirements. The mechanism supports coordination between technological implementation, organizational planning, workforce participation, resource allocation, risk management, and performance evaluation. In this structure, strategic project management provides the organizational connection between the technological capabilities of Industry 4.0 and the human-centric requirements of Industry 5.0.

The distinguishing feature of the proposed framework is therefore not the individual use of predictive maintenance technologies or Industry 5.0 principles, which have already been addressed in previous studies. Its main contribution is the explicit positioning of strategic project management as an integration layer between digital maintenance technologies and human-centric organizational transformation. This perspective connects maintenance digitalization with project objectives, organizational resources, risks, stakeholders, workforce requirements, and long-term performance considerations. The framework consequently provides a structured view of how technological, organizational, and human dimensions can be considered within the same maintenance transformation process.

Expected Outcomes

The integration of these dimensions is expected to support improvements in maintenance efficiency, equipment reliability, resource utilization, and strategic alignment. At the organizational level, the framework also addresses resilience, sustainability, workforce participation, and the coordination of maintenance initiatives with longer-term business objectives. These expected outcomes provide a basis for further empirical examination of the proposed relationships and for the development of project-based implementation approaches in industrial maintenance systems.

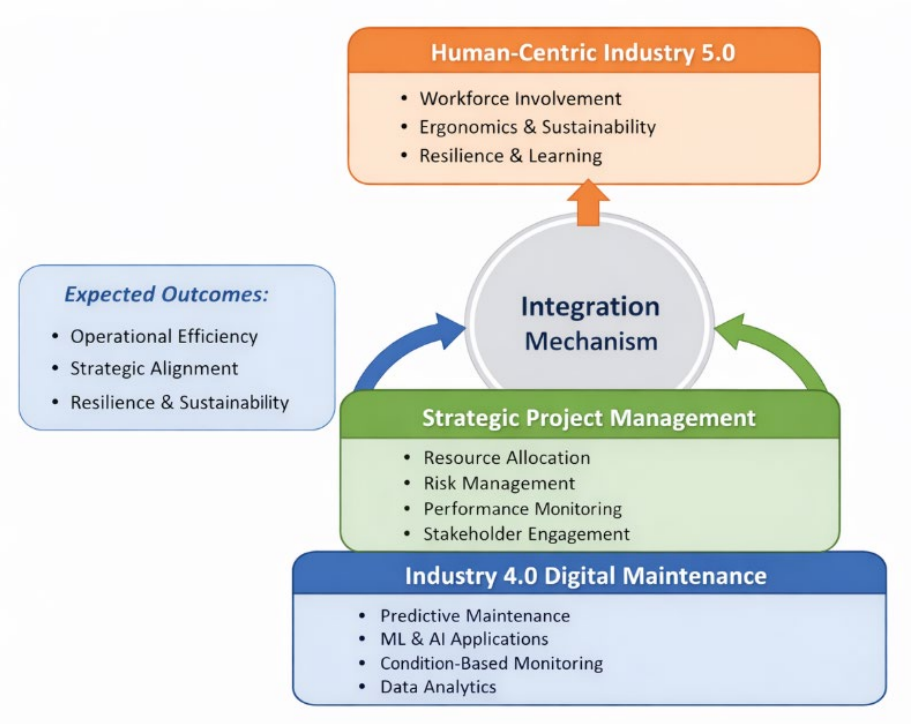


Fig. 1. *Conceptual framework linking Industry 4.0 predictive maintenance technologies, strategic project management, and human-centric Industry 5.0 principles*

RESULTS AND DISCUSSION

The reviewed literature indicates that the development of industrial maintenance systems can be considered through three interconnected dimensions: digital maintenance technologies, organizational and strategic management, and human-centric Industry 5.0 principles. The analysis of the selected studies shows that these dimensions are frequently addressed separately, while their integration within a strategic project management perspective receives less attention. The following discussion groups the main findings according to these dimensions and then considers their implications for the proposed framework.

Digitalization of Industrial Maintenance

The first group of findings concerns the application of Industry 4.0 technologies in industrial maintenance. The reviewed studies describe predictive maintenance, condition monitoring, machine learning, artificial intelligence, and real-time data analysis as important components of digital maintenance systems (Taoufyq et al., 2025; Mallioris et al., 2024). These approaches support the identification of equipment condition and maintenance requirements based on operational data and can reduce dependence on reactive maintenance practices.
Several studies also emphasize the development of analytical and predictive models for maintenance decision-making (Carvalho et al., 2021; Murtaza et al., 2024). However, the reviewed literature indicates that technical performance is often the primary focus of such approaches. Issues related to organizational integration, project planning, resource coordination, and long-term implementation are addressed less extensively. This finding supports the need to consider digital maintenance as part of a broader organizational transformation rather than as an isolated technological initiative.

Organizational and Strategic Integration

The second group of findings concerns the organizational conditions required for successful implementation of digital maintenance systems. Studies addressing maintenance

management and digital transformation emphasize the importance of planning, organizational coordination, and management practices alongside technological capabilities (Softić, 2024; Rios et al., 2024; Achouch et al., 2022).

The literature also indicates that predictive maintenance implementation requires changes in organizational processes and responsibilities. Digital maintenance initiatives may involve investments in technologies, employee competencies, data infrastructure, and coordination between different organizational functions. These requirements create a project-oriented dimension that is not fully represented when maintenance digitalization is considered only from a technological perspective.

Strategic project management provides a framework for addressing these requirements through project objectives, resource allocation, risk management, stakeholder coordination, and performance monitoring. In the context of the proposed model, these activities connect maintenance technology implementation with organizational priorities and longer-term business objectives. This represents the main link between the findings from the literature review and the proposed conceptual framework.

Industry 5.0 and Human-Centric Maintenance

The third group of findings relates to the transition from Industry 4.0 toward Industry 5.0. The reviewed literature emphasizes human-centricity, resilience, sustainability, and the interaction between people and advanced technologies (Benhanifia et al., 2025; Ramzan & Reforgiato, 2025). These principles extend the technological perspective of Industry 4.0 by placing greater attention on workforce participation, human expertise, and organizational adaptation.

For industrial maintenance, this perspective is relevant because predictive systems do not eliminate the need for human decision-making. Maintenance personnel interpret information generated by digital systems, combine it with operational experience, and make decisions according to specific equipment and production conditions. The implementation of Industry 5.0 principles therefore requires attention to employee competencies, continuous learning, ergonomics, and cooperation between workers and digital technologies.

Integration of the Main Findings

The comparison of the three groups shows a common pattern in the reviewed literature. Digital technologies provide the technical basis for predictive and condition-based maintenance, while organizational management determines how these technologies are planned, implemented, and coordinated. Industry 5.0 adds human-centricity, resilience, and sustainability to this relationship.

The proposed framework combines these dimensions by positioning strategic project management between digital maintenance capabilities and human-centric organizational transformation. This structure differs from approaches that primarily focus on predictive maintenance technologies or on individual Industry 5.0 principles. Strategic project management is used as the connecting layer through which technological initiatives can be aligned with organizational objectives, resources, risks, stakeholders, and workforce requirements.

Implications for Industrial Maintenance Management

The findings have several implications for the management of industrial maintenance systems. First, digital maintenance initiatives should be considered in relation to organizational objectives rather than only technical performance. Second, implementation requires coordination of technological investments with resources, responsibilities, employee competencies, and project risks. Third, the transition toward Industry 5.0 requires greater attention to human participation and the interaction between maintenance personnel and digital systems.

These findings support the proposed conceptual framework as a structured model for considering technological, organizational, and human dimensions together. The framework does not replace existing predictive maintenance or Industry 5.0 approaches. Instead, it provides a project management perspective for connecting these approaches within an organizational transformation process.

Research Gaps and Future Directions

The reviewed literature also identifies several areas that require further research. Empirical studies are needed to test the relationships between strategic project management practices and the performance of digital maintenance initiatives. Further research could examine project-based implementation models for predictive maintenance and investigate how organizational resources, employee competencies, stakeholder participation, and risk management affect implementation outcomes.

Another relevant area concerns human-technology interaction in Industry 5.0 maintenance environments. Future studies could examine how maintenance personnel interact with predictive systems, how digital competencies develop during implementation, and how human expertise can be incorporated into maintenance decision-making processes. Such research would provide an empirical basis for evaluating and further developing the proposed conceptual framework.

CONCLUSION

The transition from Industry 4.0 toward Industry 5.0 introduces new requirements for the management of industrial maintenance systems. The reviewed literature shows that predictive maintenance, artificial intelligence, machine learning, condition monitoring, and real-time data analytics provide important technological capabilities for digital maintenance. However, technological implementation alone does not address organizational planning, resource coordination, risk management, stakeholder engagement, and workforce requirements.

The analysis indicates that strategic project management can provide an organizational connection between digital maintenance technologies and broader business objectives. In the proposed framework, strategic project management is positioned as an integration layer connecting Industry 4.0 digital maintenance capabilities with human-centric Industry 5.0 principles. This perspective brings technological implementation, organizational requirements, and human factors into a common framework for managing maintenance transformation initiatives.

The proposed conceptual framework therefore combines three main dimensions: digital maintenance technologies, strategic project management, and human-centric Industry 5.0 principles. Its distinguishing feature is the explicit integration of strategic project management into the transition toward human-centric digital maintenance. The framework considers project objectives, resources, risks, stakeholders, performance monitoring, workforce participation, and organizational adaptation together with technological implementation.

The study contributes a structured conceptual perspective for understanding how industrial maintenance digitalization can be coordinated with organizational and human requirements. The framework can support further consideration of maintenance transformation as an organizational project rather than only as a technical implementation. It also provides a basis for developing project-based approaches to the implementation of predictive maintenance and Industry 5.0 principles.

The main limitation of the study is its conceptual nature. The proposed relationships have not been empirically tested in specific industrial organizations, and the framework therefore requires further validation. Future research should examine the framework through empirical studies and case-based applications, with particular attention to project management practices, organizational barriers, employee competencies, stakeholder participation, risk management, and maintenance performance.

Further research should also investigate how human expertise and digital technologies can be coordinated within Industry 5.0 maintenance environments. Empirical validation could provide additional evidence regarding the relationships between strategic project management, digital maintenance implementation, and organizational performance.

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