

Intelligent Ship Engine Rooms: A Decade of Progress and Challenges

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The dual pressures of rapid digitalization and increasingly stringent emissions regulations are accelerating the development of intelligent ship engine room technologies. This literature review (2014 – 2024) elucidates the current state, technological maturity, and research trends within this domain. Applying the PRISMA 2020 methodology, a pool of 410 publications sourced from Scopus, Web of Science, and Google Scholar was screened. The analysis distilled five dominant research domains: AI-based diagnostics and predictive maintenance, monitoring and automation, energy efficiency and hybrid propulsion, digital twins, and condition-monitoring frameworks. Findings indicate substantial progress in modelling, optimization, and machine learning applications. However, validation is predominantly confined to simulations or laboratory settings, lacking robust testing under real-world ship operating conditions. This underscores a persistent gap between theoretical development and practical implementation, suggesting a transitional maturity stage. The paper concludes by delineating key challenges and future research priorities essential for enabling the large-scale, real-world deployment of intelligent engine systems, thereby fostering safer and more sustainable maritime operations.

KEYWORDS

- ~ Artificial intelligence
- ~ Digital twin
- ~ Engine room automation
- ~ Intelligent ship systems
- ~ Maritime diagnostics
- ~ Predictive maintenance
- ~ Ship energy efficiency
- ~ Smart engine room

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1. INTRODUCTION

The maritime industry is undergoing a profound digital transformation, driven by stricter environmental regulations, the need for higher energy efficiency, and the rapid advancement of data-centric technologies such as the industrial Internet of Things (IoT) and Artificial Intelligence (AI) (Ferrari et al., 2025, IMO 2020 – cutting sulphur oxide emissions, Mauro et al., 2023). Within this context, intelligent engine rooms have emerged as an integrated concept combining advanced sensing, automated control, continuous condition monitoring, and data-driven optimization to enhance safety, reliability, and fuel efficiency on board (Ferrari et al., 2025, Noel et al., 2025, Zhang et al., 2023b).

The International Maritime Organization (IMO) has set ambitious decarbonization targets: a 40% reduction in CO₂ by 2030 and 70% by 2050 compared with 2008 levels (IMO Strategy on Reduction of GHG Emissions of Ships, IMO 2020 – cutting sulphur oxide emissions). Achieving these goals requires not only the adoption of alternative fuels but also demands intelligent systems capable of optimizing engine performance and maintenance in real time (Simon et al., 2024). Digitalization has therefore become an operational necessity for modern shipping, essential for both regulatory compliance and sustainable fleet operation (Munim et al., 2020, Noel et al., 2025).

Recent advances in IoT infrastructures, data analytics, and AI-supported decision systems have enabled new approaches to engine room monitoring and optimization (Munim et al., 2020, Simon et al., 2024). Big-data techniques enable large-scale integration and analysis of sensor data from shipboard machinery, providing the basis for advanced fault diagnostics and real-time condition monitoring (Cheliotis et al., 2020, Orhan and Celik, 2023, Patil et al., 2025, Theodoropoulos et al., 2021). Data-driven approaches allow early identification of deviations from normal operation, facilitating proactive maintenance and improving overall operational reliability (Cheliotis et al. 2020). Machine learning and computer vision systems further extend these capabilities by supporting automated anomaly detection and machinery status evaluation (Patil et al., 2025, Theodoropoulos et al., 2021).

The concept of the intelligent engine room consolidates these developments by interconnecting propulsion, auxiliary systems, control units, and monitoring platforms into a cohesive, adaptive environment. Such systems aim to learn from operational data, optimize performance parameters, and support semi-autonomous or fully autonomous decision making (IMO 2020 – cutting sulphur oxide emissions, Jahanbakht et al., 2020, Zhang et al., 2023a). However, despite growing interest, research in this area remains fragmented. Many authors focus on isolated components, such as condition monitoring, hybrid propulsion, or digital twins (DT), often limited to laboratory or simulations settings and without real-world applicability (Simon et al., 2024, Zhang et al., 2023a).

The purpose of this paper is to provide a data-driven overview of the research landscape on intelligent ship engine rooms and to evaluate the scientific maturity of this emerging field. The main objective is to identify research trends, technological focus areas, and methodological approaches through a structured thematic review of studies published between 2014 and 2024. To achieve a high level of objectivity, this paper applies a systematic literature review approach based on the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework (Moher et al., 2009, Page et al., 2021). This framework is widely recognized as a global standard for ensuring transparency, reproducibility, and methodological rigor in research synthesis (Tadić et al., 2025), allowing for a structured identification of key developments in intelligent engine rooms. While other methodologies exist, such as the Kitchenham guidelines specifically tailored for software engineering or the Wohlin snowballing technique for iterative reference tracking, the PRISMA 2020 framework was selected for its comprehensive reporting structure and its effectiveness in mapping the transitional maturity of maritime technologies. Using the PRISMA 2020 framework, this paper analyses publication trends and thematic clusters, and examines which intelligent engine room concepts have progressed from theory and simulation to real maritime applications.

Accordingly, this paper addresses the following overarching research question: To what extent has the concept of the intelligent ship engine room progressed from theoretical and laboratory research toward real-world maritime applications, and what patterns can be observed across research themes, regions, and validation settings?

To operationalize this, three sub-questions are examined:

1. Which technological advancements are most critical for the practical implementation of intelligent ship engine rooms?
2. How do different countries and research groups compare in their approaches to developing intelligent engine room technologies?
3. What challenges hinder the transition from theoretical and simulation-based research to real-world maritime applications?

This paper hypothesizes that current research remains predominantly conceptual or simulation-based, with limited onboard validation. By synthesizing existing knowledge, this review aims to highlight research gaps, provide insights into technological maturity, and offer guidance for future scientific and industrial efforts.

The remainder of this paper is structured as follows: Section 2 details the review methodology, including the database search strategy and inclusion criteria. Section 3 summarizes the main findings. Section 4 discusses key implications and challenges and also concludes with recommendations for future work.

2. MATERIALS AND METHODS

A literature review was conducted to analyze the development of intelligent ship engine room technologies between 2014 to 2024. The review followed the PRISMA 2020 guidelines (Georgopoulos et al., 2017, Page et al., 2021), ensuring transparency, replicability, and methodological consistency throughout the process.

The methodological framework of this review follows the PRISMA 2020 guidelines, ensuring transparency and reproducibility of the literature screening process. Similar approaches have been successfully implemented in engineering-oriented reviews (Angelescu et al., 2023). The methodological framework includes four sequential phases: identification, screening, eligibility, and inclusion, followed by synthesis stage in which the selected papers were evaluated in detail. The overall workflow of this paper is presented in Figure 1.

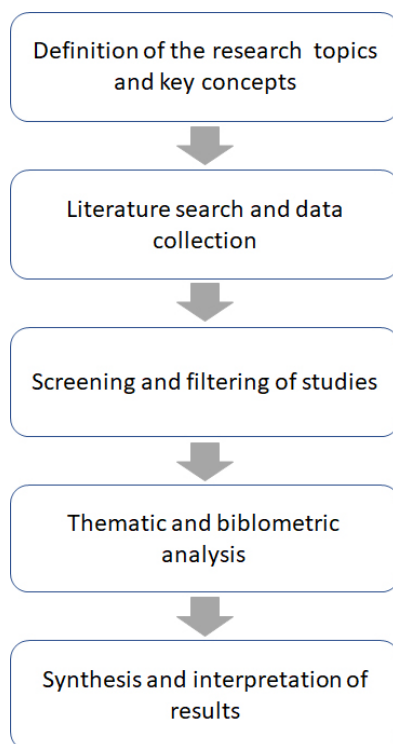


Figure 1. Flowchart of the literature review based on PRISMA 2020 methodology

The literature search was conducted across three major scientific databases commonly used in maritime engineering, maritime technology, and automation research: Web of Science (WoS), Scopus, and Google Scholar. The search covered the period from 2014 to 2024, reflecting a decade of advancements in intelligent ship systems. Database-specific Boolean operators and keyword combinations were applied to capture papers on intelligent engine room and intelligent maritime technologies. An overview of the databases and search terms is provided in Figure 2.

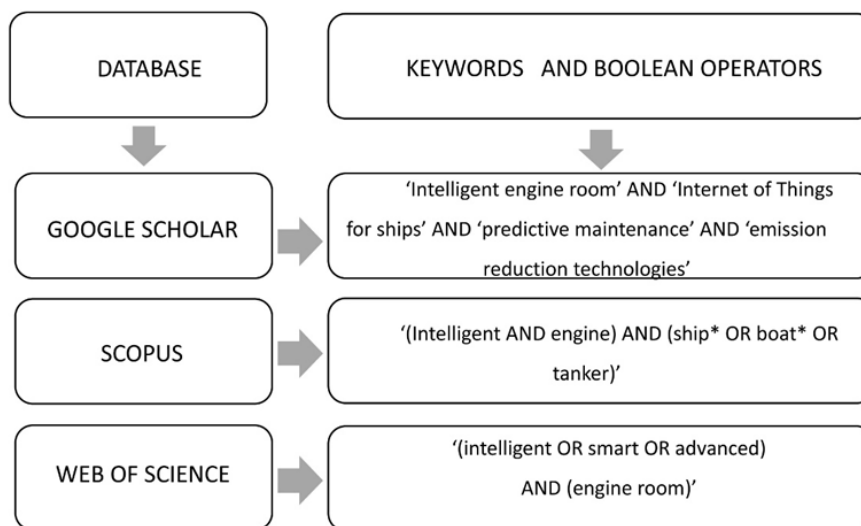


Figure 2. Overview of databases and keywords

Following the database selection process, the search strategy was structured according to PRISMA 2020 principles, which emphasizes the need for keywords clustering and thematic filtering (Page et al., 2021). The papers captured through the keyword search and databases presented in Figure 2 were evaluated according to technological focus, research objectives, methodological approach, validation environment (simulation, real-world testing), and country of origin based on institutional affiliation. Recurring patterns across the literature were to categorize the papers into five thematic groups representing the primary research directions within the field:

1. Condition monitoring and fault diagnostics,
2. Automation and control systems,
3. Energy optimization and hybrid propulsion,
4. AI and predictive analytics, and
5. Digital twins and cyber-physical integration.

This combined approach enabled a detailed interpretation of the scientific focus of each paper and comprehensive assessment of the technological maturity of research related to intelligent ship engine rooms. The synthesis and interpretation of results are presented in the following section. Applying PRISMA guidelines within technical domains such as machine learning has proven effective in maintaining methodological clarity and reproducibility (Ionescu et al., 2024). This approach inspired the systematic structure of the present review.

3. RESULTS AND DISCUSSION

The analysis of the identified papers provides a comprehensive overview of the scope, thematic orientation, and developmental trajectory of research on intelligent ship engine rooms between 2014 and 2024. The initial database search across Scopus, Web of Science, and Google Scholar retrieved 410 publications. After removing duplicates and conducting a structured screening of titles and abstracts, 45 unique papers remained. The full identification, filtering, and selection workflow was conducted in accordance with PRISMA 2020 guidelines, as shown in Figure 3.

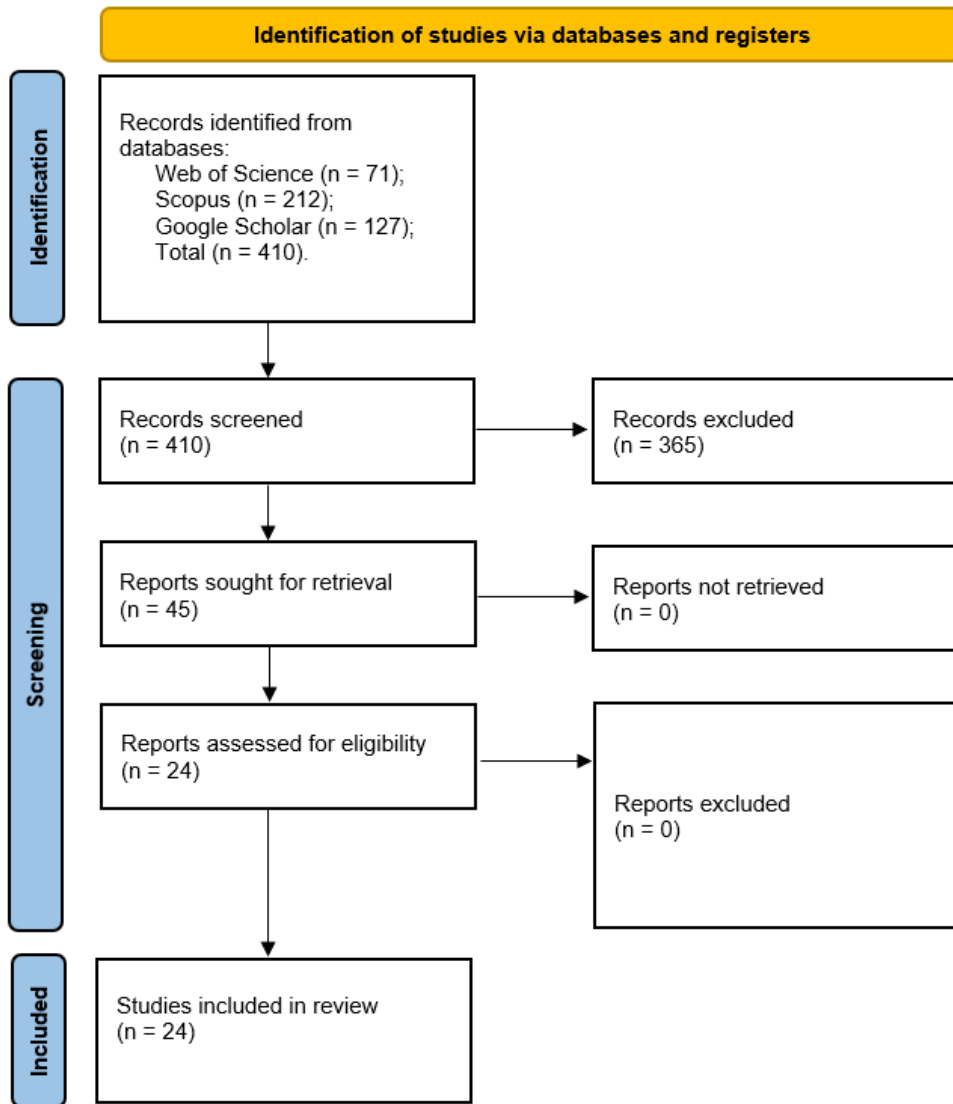


Figure 3. PRISMA 2020 flow diagram of the identification and selection process

According to Figure 3, the PRISMA-based workflow clearly demonstrates the approach applied to obtain a representative and high-quality dataset for analysis. The initial scope (of 410 records) consisted of 212 papers from Scopus, 127 from Google Scholar, and 71 from Web of Science. After deduplication and relevance screening; 45 papers remained. Applying the final eligibility criteria, which included publication in English, peer-review status, and focus on intelligent ship engine rooms or related intelligent maritime technologies, and also available documents, resulted in the inclusion of 24 studies for detailed examination. Potential selection bias was mitigated by using three complementary databases and predefined inclusion criteria. Nevertheless, the exclusion of non-English publications and gray literature may limit the generalizability of the findings.

The presentation of the identification, screening, and inclusion stages was formatted according to the standardized flow (flowchart) of the PRISMA reporting methodology, offering a clear and visually structured depiction of the process (Patha et al., 2023). The data selection and exclusion criteria were developed according to best practices defined in the uploaded PRISMA 2020 statement (Yao et al., 2022), emphasizing clear reporting of excluded studies and their rationale.

To further clarify the composition of the final dataset, the selected papers were categorized by source databases. Scopus contributed the largest share (14 papers, 58.3%), reflecting its strong indexing of engineering, automation, and computer science journals, where intelligent maritime systems are most frequently reported. Google Scholar accounted for seven papers (29.2%), capturing emerging, interdisciplinary, and conference-based research that is often not yet indexed in traditional databases. Web of Science contributed 3 papers (12.5%), representing a smaller but highly curated subset of established peer-reviewed literature.

Establishing the structure and source distribution of the final dataset provides a necessary foundation for the subsequent quantitative analyses. The next part of this section, therefore, explores the temporal dynamics of publication

activity and the geographical distribution of research contributions, enabling the identification of publication trends and leading research regions in this emerging field.

3.1. Publication Trends and Geographical Distribution of Research

A quantitative assessment of the selected publications was conducted to identify temporal patterns in research activity and the geographical distribution of contributing institutions. These aspects provide insight into how interest in intelligent ship engine room technologies has evolved over time and which countries are leading scientific contributions in this field. The annual distribution of relevant papers is shown in Figure 4.

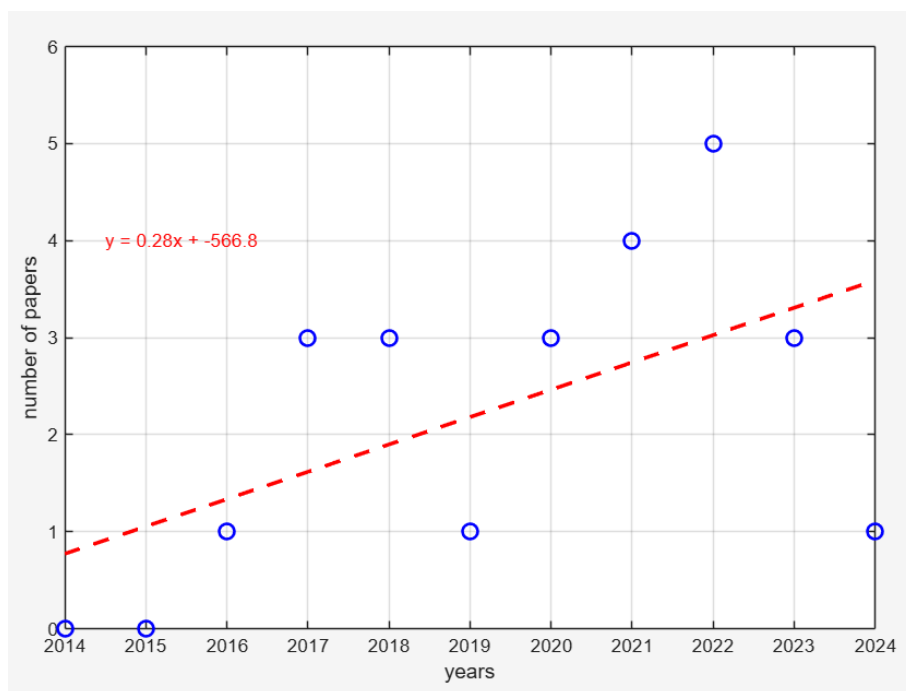


Figure 4. Number of relevant paper publications per year

Figure 4 presents the annual distribution of publications from 2014 to 2024, along with the fitted linear trend line. The positive slope of the trend line ($m = 0.28$) indicates a consistent long-term increase in research activity, corresponding to an average annual growth of approximately one additional publication every 3.5 years. When expressed as an angular measure, the slope represents a growth angle of 15.7° , further confirming an upward trajectory in the scientific output of this field.

Although the overall trend is positive, several short-term fluctuations are visible. The decrease in 2019 aligns with the onset of the COVID-19 pandemic, which constrained laboratory access, shipboard testing, and fieldwork essential for engineering research. The reduced number of publications recorded in 2024 is most likely related to indexing delays and incomplete database updates rather than a genuine decline in research output. In contrast, the peak observed in 2022 reflects intensified global attention on digitalization, AI-driven diagnostics, and decarbonization requirements in maritime operations.

Overall, the trend analysis demonstrates a clear and measurable expansion of scientific interest in intelligent ship engine rooms over the past decade, providing quantitative evidence that the field is steadily developing and gaining academic visibility.

Building on the observed growth in publication activity, the next step in the analysis focuses on identifying the country's leading research on intelligent ship engine rooms and the contributing most to the development of related technologies. The geographical distribution of the analyzed papers is presented in Figure 5, based on the institutional affiliations of the authors retrieved from the Scopus, Web of Science, and Google Scholar databases. In cases where publications involved authors from different countries, the country of the corresponding author's institutional affiliation was used to determine national representation. This approach ensured consistency in counting while also acknowledging the international and collaborative nature of research within this domain.

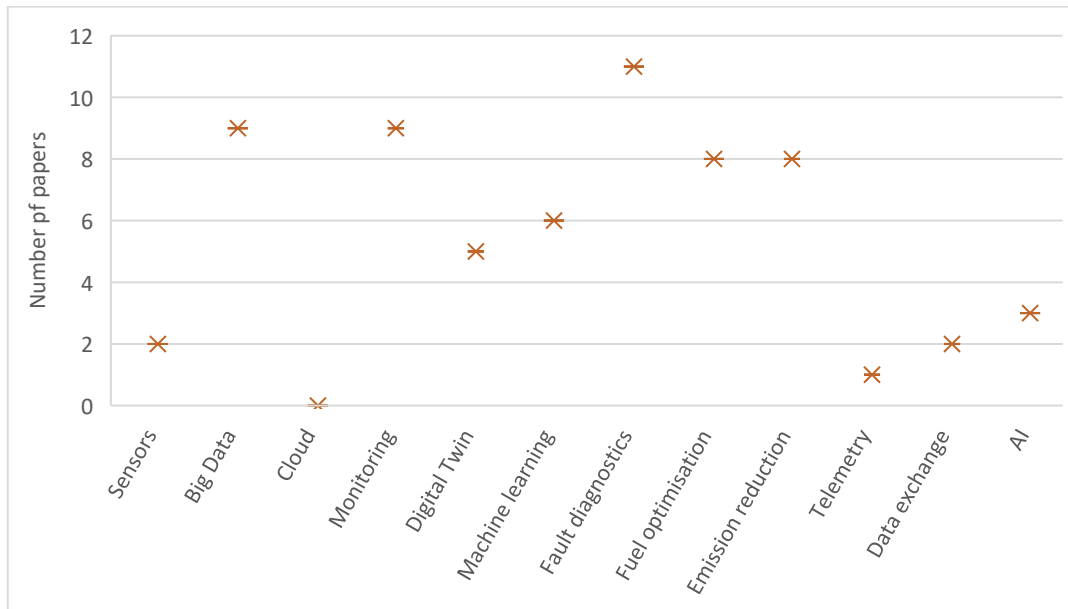


Figure 8. Terms in papers reflecting their main research focus areas

Overall, Figure 8 demonstrates that most studies concentrate on diagnostics, monitoring, and optimization, confirming a strong research orientation toward operational efficiency, automation, and sustainability in the evolution of intelligent ship engine systems. According to Figure 8, the term *fault diagnostics* appears most frequently, with 11 papers addressing it, highlighting its central role in research on the reliability and operational safety of intelligent maritime propulsion systems. The topic of *Big Data and monitoring are closely related, each represented by nine papers*, underscoring the growing importance of data-driven monitoring processes for performance optimization and predictive maintenance. Environmental and operational performance considerations are also prominently represented. *Fuel optimization* and *emission reduction*, each present in eight publications, point to the growing importance of energy efficiency and regulatory compliance as drivers of intelligent engine system development. Recent studies also highlight the importance of integrating regulatory tools such as the Energy Efficiency Operational Indicator (EEOI) into daily ship operations to balance freight transportation effectiveness with environmental constraints (Melnyk et al., 2022). Advanced computational approaches are further evident through the occurrence of *machine learning* (six papers) and *DT* (five papers), demonstrating the expansion of simulation-based modelling and predictive analytics in maritime engineering. By contrast, terms such as *data exchange*, *sensors*, *AI*, and *telemetry* appear less frequently, suggesting that although these components are essential for system connectivity and integration, they remain underexplored in current maritime research.

To synthesize these thematic patterns, the 24 studies were grouped into five major research categories that represent the core directions of scientific inquiry in the field Engine Room Condition Monitoring and Data Imputation, Engine Room Monitoring and Automation, Energy Efficiency and Hybrid Energy Systems, AI and Machine Learning for Diagnostics and Predictive Maintenance, DT in Maritime Systems - exploring virtual representations of machinery, lifecycle simulations, and predictive capabilities. The integration of DT architectures with operation-and-maintenance processes has been shown to improve decision-making and asset reliability (Werbińska-Wojciechowska et al., 2024). The concept of maritime DT is rapidly evolving, with research highlighting synchronization and interoperability challenges between physical and virtual assets (Madusanka et al., 2023). A real-time DT model for ship structural deformation monitoring, proving the feasibility of physics-based integration with onboard sensors (Wei et al., 2024). Recent progress in hybrid diagnostic models, such as the DASVR-based method for marine diesel engines proposed by (Chen et al., 2024), illustrates the practical value of AI in real-time condition monitoring. The distribution of studies across these five groups is shown in Figure 9.

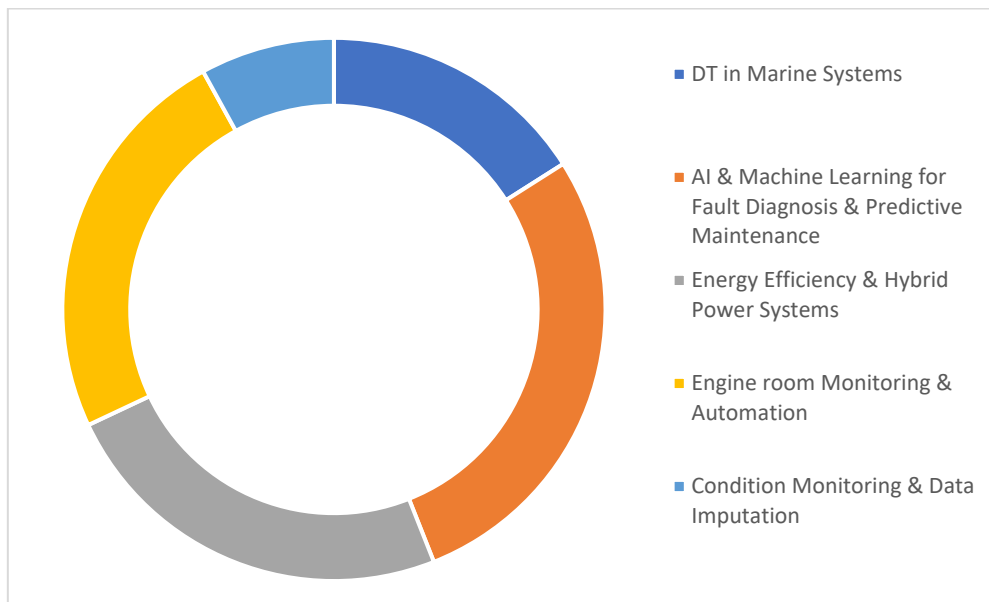


Figure 9. Distribution of papers by main research focus

According to Figure 9, the most represented category is *AI and Machine Learning for Diagnostics and Predictive Maintenance*, highlighting the field's strong orientation toward data-driven approaches and intelligent models for machinery health assessment. The groups *Engine Room Monitoring and Automation* and *Energy Efficiency, and Hybrid Energy Systems* reflect a balanced focus on operational optimization and automation. Fewer publications fall under *DT in Maritime Systems* and *Condition Monitoring and Data Imputation*, indicating that these areas, although technologically significant, remain less extensively developed.

Together, these findings demonstrate that contemporary research on intelligent ship engine rooms is predominantly oriented toward advanced diagnostics, predictive analytics, and optimization, while foundational aspects such as data quality, system integration, and real-world validation receive comparatively limited attention. This thematic structure provides essential context for the subsequent evaluation of the methodological robustness and practical applicability of the analyzed studies.

3.4. Discussion and Final Paper Divisions

Critical examination of all 24 selected studies was conducted to assess the methodological robustness, technological maturity, and practical applicability of current research on intelligent ship engine rooms. The papers were reviewed within the five previously identified thematic groups, enabling a structured comparative assessment of their contributions and limitations. Table 1 summarizes the main findings, presenting the representative studies in each group, their primary contributions, and the key limitations observed.

To ensure a systematic and critical evaluation of the reviewed literature, the selected studies were grouped into thematic clusters according to their primary research focus, applied methodologies, and application domains. In addition to summarizing the main scientific contributions, particular emphasis was placed on validation levels, key limitations, and unresolved research gaps that currently hinder the transfer of proposed solutions to real shipboard environments. The following table consolidates the thematic classification of the literature with a critical assessment of the identified research clusters, providing a structured overview of the current state of research and directions for future works.

Thematic group / research cluster	Representative papers	Typical approaches	Validation level	Main contributions	Key limitations	Identified research gaps
Condition monitoring and fault diagnostics (ML-based)	Feng et al. (2017), Gkerekos et al. (2017), Kowalski et al., (2017), Tan et al., (2021), Wang et al., (2023), Xu et al., (2021), Zhang et al., (2023b)	Statistical models, ML-based diagnostics, sensor data analytics	Simulation / short-term experiments	Development of intelligent fault detection and predictive maintenance frameworks	Limited datasets; lack of long-term onboard data	Need for fleet-scale datasets and robust validation under real operating conditions
AI and predictive analytics	Feng et al. (2017), Gkerekos et al. (2017), Kowalski et al., (2017), Tan et al., (2021)	CNN, DBN, Transformer-based models	Laboratory / simulation	Automated fault diagnostics and degradation prediction	Overfitting; limited model explainability	Absence of standardized benchmarks and onboard validation
Engine room monitoring and automation	Cao et al. (2020), Michailidis et al., (2019), Shang et al., (2022), Yao et al., (2024), Zhelezniak (2016), Zou et al., (2023)	Rule-based control, subsystem automation, vision-based monitoring	Prototype / laboratory	Automated control, visual recognition, and subsystem integration	Focus on isolated subsystems; weak system interaction analysis	Missing interoperability and cyber-physical safety evaluation
Energy efficiency and hybrid propulsion systems	Bhati et al., (2022), Bui et al., (2022), Kanckos et al., (2018), Ma et al., (2018), Tay et al., (2021), Yang et al., 2020	Optimization algorithms, EMS models, hybrid simulations	Simulation-based	Optimization of fuel consumption, emissions, and hybrid power management	Economic feasibility rarely addressed	Lack of lifecycle cost analysis and real fuel-saving validation
Digital twins and cyber-physical integration	Miri (2018), Stoumpos (2020), Wu et al., (2021), Zhang et al., (2023a)	Physics-based models, co-simulation	Conceptual	Lifecycle modeling and support for predictive maintenance and simulation	Digital twins often reduced to virtual models	Lack of real-time synchronization and cybersecurity assessment
Data integrity and imputation in condition monitoring	Gkerekos et al. (2017), Velasco-Gallego and Lazakis (2020)	Missing-data handling, sensor reliability analysis	Limited experimental datasets	Sensor data integrity improvement and early fault detection	Small datasets; short-term or single-system validation	Development of scalable methods for multi-system and fleet-level applications

Table 1. Integrated thematic classification and critical assessment of the literature

Table 1 summarizes the main contributions, methodological approaches, and limitations identified in each paper, enabling a clear overview of prevailing research directions in intelligent ship engine rooms. The most prominent advancements are in the group focusing on AI Machine Learning for Diagnostics and Predictive Maintenance, where numerous papers introduce innovative classification models, neural networks, and deep learning architectures for automated fault diagnosis. Although these methods exhibit strong performance in controlled conditions, the majority rely on simulated datasets or laboratory-generated signals, which limits their validation under real ship operating conditions. The integrated assessment reveals that, despite notable methodological advancements, the majority of existing studies remain constrained by limited validation in real shipboard environments. A strong reliance on simulations and laboratory experiments, fragmented subsystem-level analyses, and the scarcity of long-term and fleet-scale datasets represent the primary barriers to large-scale industrial adoption. Consequently, future research should prioritize integrated and interoperable architectures,

explainable and robust AI models, and comprehensive onboard validation strategies, while explicitly addressing economic feasibility, cybersecurity, and operational reliability under real maritime conditions.

Research on Energy Efficiency and Hybrid Energy Systems has made significant progress in model-based optimization of propulsion configurations, energy management, and emission reduction. In contrast to capital-intensive hardware upgrades, Melnyk et al., 2022 demonstrate that existing vessels can meet strict environmental standards (EEDI/EEOI) through operational measures such as speed optimization and effective use of the Ship Energy Efficiency Management Plan (SEEMP), without the need for costly modernization. However, studies in this category commonly lack long-term empirical testing or full-scale economic feasibility analyses, which are essential for assessing their real-world applicability on commercial vessels.

In the thematic group addressing *Engine Room Monitoring and Automation*, substantial work has been carried out on integrating automated control systems, sensor fusion, and machine vision tools. Despite demonstrating important advancements, these studies typically examine isolated subsystems without addressing broader interoperability issues or cybersecurity considerations that are crucial in fully integrated intelligent engine rooms.

Research on DT in maritime systems indicates that although interest is growing, the concept is often misused with many works treating simple virtual models as digital twins, whereas true mutual data exchange between physical and virtual environments is largely missing (Mauro et al., 2023). However, the term Digital Twin is typically abused in the shipping industry, many times erroneously referring to any virtual version of a model-based system as a Digital Twin of the ship the basis of a true Digital Twin is mostly missing, confusing a virtual model with a sophisticated living virtual environment. Key modelling and calibration limitations for DT in maritime applications have been critically discussed by (Assani et al., 2022), whose findings reinforce the need for field-validated models. Although digital twins and cyber-physical integration are identified as a distinct research cluster, the analysis shows that most studies focus on virtual modelling, while true cyber-physical integration, including real-time data exchange and cybersecurity considerations, remains largely unexplored.

Finally, the group on *Engine Room Condition Monitoring and Data Imputation* highlights essential challenges related to data integrity, missing sensor data, and performance deviations. Although these contributions are fundamental to reliable intelligent systems, they are supported by relatively small datasets and short-term experiments, underscoring the need for broader empirical foundations.

Overall, the synthesis of findings across all groups reveals a clear pattern: *theoretical models, simulation-based experiments, and laboratory studies dominate the current research landscape*, while practical, onboard validation remains scarce. This creates a persistent gap between conceptual development and real-world deployment. Only a limited number of studies demonstrate the feasibility of intelligent systems under actual maritime conditions, underscoring the need for future work that integrates laboratory-developed solutions into operational ship environments.

The comparison of research interests and validation environments, summarized in Figure 10.

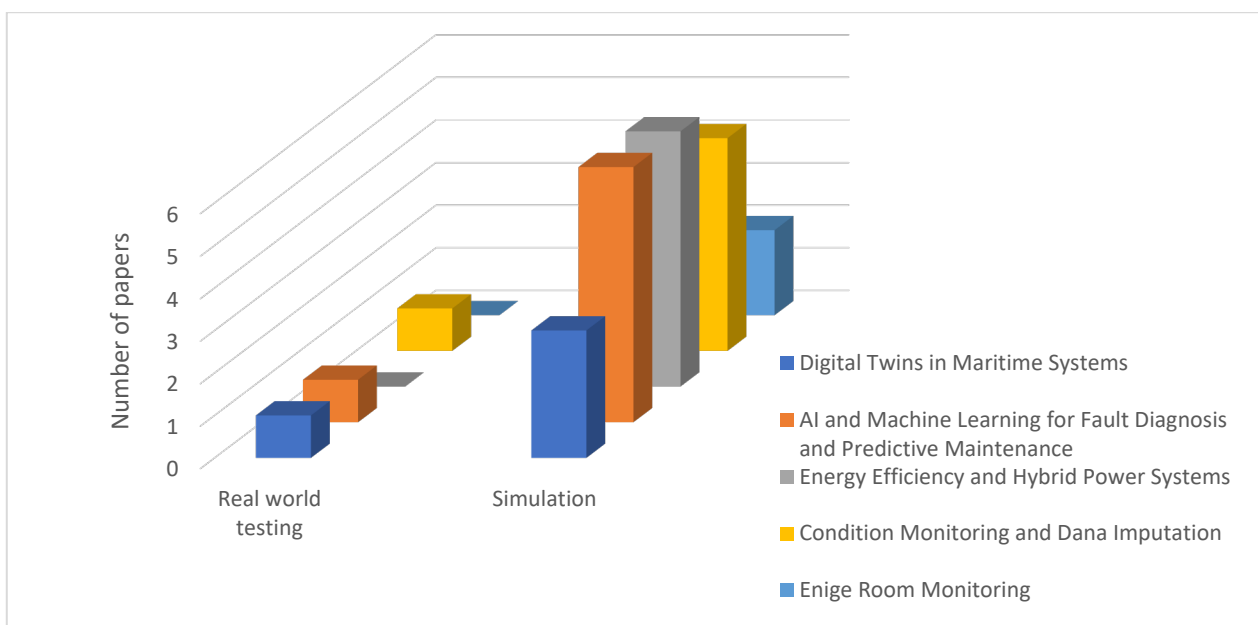


Figure 10. Comparison of the number of studies by research interest and type of assessment

According to Figure 10, only a small subset of studies reported testing under real navigation conditions or during authentic engine loads. This imbalance underscores a persistent divide between theoretical development and practical deployment, indicating that intelligent engine room technologies are advancing rapidly in concept but remain limited in operational maturity.

The dominance of experimental and simulated validation environments highlights a critical gap in the current research landscape: the lack of comprehensive, long-term, and real-world performance evaluations. Without such evidence, the reliability, robustness, and scalability of intelligent systems cannot be fully confirmed. This reveals the need for a substantial shift in research methodology, moving beyond conceptual models toward field trials and onboard integration.

These observations point to several strategic priorities for future research. Emphasis should be placed on expanding real-world case studies, improving sensor data quality and the availability of long-term datasets, developing interoperable and secure system architectures, and establishing standardized frameworks for testing and certification. The convergence of these efforts is essential to transition intelligent engine room technologies from experimental prototypes to fully operational systems capable of supporting safer, more efficient, and sustainable maritime operations.

3.5. Technology Readiness, Implementation Barriers and Cyber-physical Risks

Despite frequent references to the gap between theory and practice, most reviewed intelligent engine room technologies remain at TRL levels 3-5, corresponding to experimental proof-of-concept and laboratory validation. Only a limited number of the monitoring and automation solutions approach TRL 6, where subsystem demonstration in a relevant maritime environment is achieved.

The transition from prototype systems to fleet-wide deployment are constrained not by algorithmic immaturity, but by critical structural and operational barriers. These include the absence of standardized certification procedures for AI-based systems and limited compatibility with legacy shipboard automation architectures. However, the most significant impediment to higher TRL achievement is the emergence of new cyber-physical risks which are currently insufficiently addressed in the literature (Fruth et al. 2017).

The increasing intellectualization of the engine rooms significantly expands the attack surface of shipboard architectures. AI-driven diagnostics, digital twins, and interconnected monitoring systems introduce vulnerabilities such as data manipulation, sensor spoofing, and unauthorized control interventions. A major limitation identified is the widespread absence of cybersecurity-by-design principles, most reviewed papers lack secure data exchange protocols and redundancy mechanisms necessary for safe operation. Furthermore, insufficient integration with critical ship systems, such as power management and navigation networks, creates a risk where faults or cyber incidents could propagate beyond the engine room, compromising overall vessel safety.

Therefore, bridging the gap between theory and practice requires more than algorithmic refinement. Future intelligent engine room architectures must incorporate cybersecurity assessment, rigorous system interaction analysis, and compliance with emerging maritime cyber-risk guidelines as integral design requirements rather than post-deployment considerations.

4. CONCLUSION

A systematic and comprehensive examination of research on intelligent ship engine rooms published between 2014 and 2024 is presented by this paper. Using the PRISMA 2020 methodology, 24 relevant studies were identified from an initial set of 410 records, enabling a transparent and structured assessment of technological progress in this rapidly developing field. The review showed substantial advancements in several areas, including simulation-based modelling, hybrid energy optimization, autonomous monitoring, and especially AI-driven diagnostics and predictive maintenance. Five dominant thematic domains were identified, illustrating the multidisciplinary character of intelligent engine room research and its alignment with broader trends in maritime digitalization.

Despite these achievements, the findings clearly indicate that research activity remains heavily concentrated in laboratory settings and controlled simulation environments. Only a small number of studies reported validation during real navigation or under authentic engine loads, which reveals a consistent gap between conceptual development and practical implementation. As a result, the technological maturity of intelligent engine room systems can be considered transitional, with a high level of theoretical sophistication that has not yet been systematically validated in operational maritime environments.

Addressing this gap requires a decisive shift in methodological priorities. Future research should focus on large-scale onboard testing, long-term performance monitoring, and the integration of intelligent systems into real ship operations. Strengthening data quality, sensor reliability, and cybersecurity will be essential for ensuring the robustness of intelligent engine room architectures. Equally important is the development of interoperable platforms and standardized evaluation frameworks that can support certification processes and facilitate wider industrial adoption.

Overall, the review highlights a field that is progressing steadily and holds significant potential to improve safety, operational efficiency, and environmental performance in the maritime sector. Realizing this potential will depend on expanding empirical validation efforts and advancing from experimental prototypes toward fully integrated intelligent engine rooms that can operate reliably under real-world conditions. Such progress is essential for supporting the broader goals of maritime decarbonization and digital transformation, ultimately contributing to safer, smarter, and more sustainable ship operations.

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CONFLICT OF INTEREST

Authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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