AI and digital transformation in the maritime industry: the case of predictive maintenance

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Abstract

This paper explores the rapid rise of artificial intelligence (AI) in the maritime industry, discussing the current state of AI adoption, its benefits, challenges, and future prospects. It also examines the latest trends and developments in AI applications, highlighting predictive maintenance, by offering insights from the real-life case of integrating data-driven condition based maintenance process to operating vessels, for enhanced operational efficiency and safety.

Keywords

Artificial Intelligence; Predictive maintenance, Data-driven Maintenance; Operational efficiency; Safety

Introduction

The maritime industry is undergoing a significant transformation driven by the adoption of artificial intelligence (AI) technologies. This paper aims to provide a comprehensive overview of the AI landscape in maritime, focusing on predictive maintenance as a key application area.

The AI landscape

The maritime AI market has seen explosive growth, nearly tripling in size over the past year. According to Thetius research, the market is now valued at USD $4.13 billion, with a projected five-year compound annual growth rate of 23%.

The number of organisations involved in developing, selling, buying, or investing in AI technologies within the maritime industry has significantly increased. According to Thetius research, in the last 12 months alone, 420 organizations have been involved in AI-related activities, compared to 276 organizations in the previous year. This growth is indicative of the rising interest and investment in AI technologies among maritime stakeholders.

Thetius research has captured 125 companies involved in supplying AI technologies within the last 12 months and 36 shipping companies that have announced the purchase or plans to deploy AI-enabled technologies.

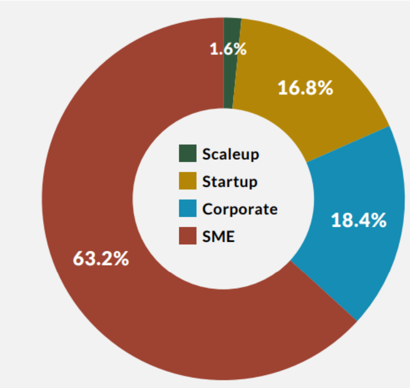

Figure 1: AI suppliers by type

The growth in SMEs and startups supplying AI technologies since the 2022-2023 research is unsurprising (Figure 1). This rise aligns with the industry's increasing demand for energy-efficient and safe operations. SMEs often specialise in niche markets or applications of AI, allowing them to offer tailored and customised solutions to meet specific needs.

AI technologies are being harnessed to optimise voyages, predict maintenance needs, enhance navigational safety, and manage energy consumption more effectively.

The case of predictive maintenance

Traditionally, vessel maintenance has primarily followed a program of scheduled inspections and reactive maintenance. These practices often lead to inefficiencies, such as over-maintenance and under-maintenance, which can result in increased operational costs and downtime. The reliance on human expertise and the limited use of sensor data further exacerbate these inefficiencies

AI-powered predictive maintenance solutions are transforming the way maritime companies manage their assets. By analysing data from sensors and other sources, these solutions can predict equipment failures before they occur, allowing for timely maintenance and reducing downtime.

Joint research between Nippon Yusen Kabushiki Kaisha (NYK Line), MTI and Lloyd's Register identified that the integration of DCBM practices, can improve the reliability and operational efficiency of vessels.

Key challenges of condition-based maintenance

Imprecise maintenance and inspection protocols

A fundamental issue with current CBM processes is a lack of precision in maintenance and inspection checklists, which often suffer from either an excessive number of included tasks or an absence of crucial maintenance activities. These shortcomings can create unnecessary added labor costs but also increase the likelihood of errors during maintenance. Furthermore, they can result in unexpected faults if essential upkeep steps are neglected. These challenges could be mitigated by an analytics-driven approach using historical and current operational data to revise and refine maintenance and inspection schedules. Implementing such a strategy would necessitate the creation of analytics-based diagnostic systems incorporating advanced diagnostic algorithms and precise measurement tools.

Deviations from scheduled maintenance and inspections

Another common issue in maintenance effectiveness is a frequent disregard for prescribed maintenance and inspection timelines. A failure to correctly follow suggested scheduled maintenance timings is often a primary causal factor in unexpected system failures. An analytics-driven remedy for this issue would be the implementation of digital platforms to accurately record maintenance activities. This could be completed in stages where complete automation of specific processes is currently impractical1.

Accuracy in condition assessment

The success of CBM can be compromised if the criteria used to identify hazardous operating conditions are vague or undefined, or if essential diagnostic data is scarce. These types of information gaps often culminate in operational failures and could lead to significant injuries if delays occur in identifying malfunctioning equipment. Analytics-driven methods can alleviate these issues by employing data analysis to uncover trends or early warning signs of unsafe operating conditions and potential system failures. To put this data into action, operators need to develop analytics-based systems that include diagnostic algorithms as well as appropriate instruments of measurement1.

Insufficient troubleshooting response

A lack of an effective response strategy outlining steps to take when faced with system failures can lead to delays in initiating required corrective actions and could lead to significant injuries. This white paper does not recommend a specific analytics-driven solution for this particular challenge, but the authors note that there is an urgent need for additional research and development in this domain.

Industry drivers for data-driven Maintenance

The potential benefits from the enhancement of shipping maintenance through the application of data also align closely with several macro-level change drivers that are currently reshaping the maritime industry, pushing shipping companies to adapt their operational processes to stay competitive, improve efficiency, and meet evolving demands. A combination of economic, regulatory, technological, and competitive factors will require the shipping sector to continue to evolve in its approach to vessel management, with data-driven maintenance likely to play an increasingly important role in ensuring that improved levels of reliability, safety, and sustainability in maritime operations are achieved going forward.

Cost efficiency and profitability

Shipping companies are under constant pressure to reduce operational costs and improve profitability. Data-driven maintenance helps to optimize maintenance spending by reducing the number of inspection, survey, and functional testing tasks required, allowing resources to be focused on carrying out required maintenance at the optimal time, minimizing unplanned downtime, and improving operational flexibility

Environmental regulations

With global goals to reduce emissions driving requirements for more efficient vessel operations, data-driven maintenance can help to reduce fuel consumption and emissions by supporting greater efficiency in the operation of machinery, while avoiding the performance of maintenance at inefficient times. Optimized maintenance can also help to reduce the carbon footprint of the spare parts and maintenance logistics activities required to service a vessel. Traditional planned maintenance typically results in the provision and storage of a large number of spare parts, some of which often remain unused beyond their expiry date. Optimized maintenance schedules will also minimize travel hours for service engineers and technical personnel attending to equipment and systems for testing and troubleshooting

Safety and risk mitigation

The increasing public visibility of incidents that occur at sea, and the consequent risks they carry for company reputations, mean that maritime operators can benefit from being seen to be adopting the latest technologies to enhance equipment safety. DCBM sits firmly within that category, helping to identify and address potential safety risks by proactively managing equipment health and reducing the likelihood of unscheduled downtime and failures. Regulators and insurers are also showing an increasing interest in data-driven maintenance procedures as a means of providing transparency in compliance processes and reducing the risk of failures in service, delivering improved confidence in vessel operations and a reduction in insurance claims.

As DCBM allows for the creation of more precise and adaptive risk models than traditional approaches by continuously collecting and analyzing data from various ship systems, the application of data-driven methodologies within the maritime industry could deliver far-reaching benefits beyond merely ensuring safe operations. Improved digitalization would support the accelerated adoption of parallel technologies that could improve operational efficiency and enable decarbonization, such as the utilization of 'digital twin' models to identify new opportunities for cost and fuel reduction. This could create savings that are similar to, if not better than those realized by early adopting industries like aviation – where US Army and FAA sources have reported that data-driven condition-based maintenance regimes for aero engines have delivered a 30% reduction in mission aborts, a 30% reduction in maintenance costs, and a 5-10% reduction in scheduled maintenance costs

Drivers for Ship Owners and Operators

Vessel owners and operators clearly stand to gain from optimized asset utilization, through increased equipment availability, reduced downtime, and lower total maintenance costs, which collectively contribute to a higher return on investment from their assets. Safety is a major driver, and the adoption of proactive measures in maintaining vessels will support the early detection of abnormalities, preventing major breakdowns and enabling flexible maintenance planning not constrained by the methods commonly found in Traditional Breakdown Maintenance (TBM) and Condition Monitoring Systems (CMS). DCBM can be expected to not only reduce the frequency of maintenance activities but to also significantly lower operational expenditure (OPEX) and crew workload. The increase in overall availability of the vessel, which can be predicted with a higher level of certainty through analysis of actual operating conditions for each particular system that is dependent on components that are subject to degradation over time, is a key consideration for owners when building a business case to demonstrate return on investment in DCBM technologies.

Some of the key benefits in this area can be delivered through management of the uptime or availability of different 'functions' of the ship, rather than individual components in isolation – for example, is the 'navigational function' available for operation, or the 'loading'? This approach requires consideration of the ship as a 'system of systems' that undertakes a range of connected functions, which each involve a certain collection of components that are required to dependably work together. The level of digitalization of such systems will determine the success of the adoption of data-driven decision-making business models and is dependent on a number of factors – including the maturity of the available technology, the cost of adapting the technology to specific requirements, the actual adoption of the technology on board real ships, and the acceptance of the analysis provided in the operational decision-making process (supervised by humans in the initial stages).

Real-life OPEX benefits

The incentive for shipping companies to adopt DCBM processes may be the easiest to quantify, as reduced maintenance spending can be directly expressed as dollar amounts.

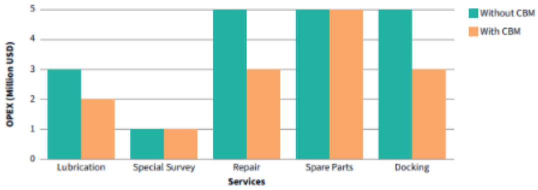

Figure 2: OPEX comparison for 10 years in service with and without CBM

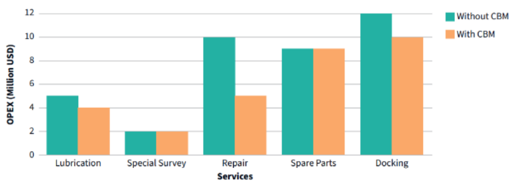

Figure 3: OPEX comparison for 20 years in service with and without CBM

The data presented at Figures 2 & 3 have been collected from operating vessels, from ships that have deployed CBM processes and those that have not. Over the years, the cumulative savings that could be accrued by vessels employing CBM become increasingly evident. Notably, the gap in maintenance costs widens with the age of the ship, underscoring the long-term financial benefits of CBM adoption. While certain services exhibit more pronounced cost reductions from CBM implementation, others showcase moderate to significant savings, contributing to overall fleet-wide cost optimisation.

The data underscore the tangible benefits that can be created through the integration of CBM strategies within the operational framework of a shipping fleet. By leveraging predictive maintenance techniques and real-time monitoring, organisations stand to significantly mitigate maintenance expenditure, enhance operational efficiency, and prolong asset lifespan.

Different Types of AI Technology in used in Condition Based Maintenance

Anomaly detection – AI that can differentiate between nominal and abnormal operating conditions. The portion of operational data (e.g. time series data) indicative of the anomaly will be further analysed to determine the existence and narrow the type of faults and failure conditions.

Fault detection and isolation - Refers to the AI processing that builds on the results of anomaly detection to evaluate and identify the specific fault/failure type (i.e. a fault is an incipient failure), the affected replaceable part(s) and the estimated severity of degradation/damage experienced by the replaceable part(s).

Diagnostics - Diagnostics follows fault detection and is defined as the AI processing and analysis of concurrent faults, failures present in the equipment. Furthermore, diagnostics includes reasoning at the sub-assembly, equipment, sub-systems and systems level to provide an integrated health assessment as a consequence of several faults and failures.

Prognostics - AI that predicts the time progression of a specific failure mode from its incipience (i.e. a fault) to the estimated time of the replaceable part failure. Given that no replaceable part exists in isolation and that are a multitude of influences at the sub-assembly, system, vessel level, including operational and maintenance i.e. real-world factors that can be technically challenging to represent, prognostics will include the probabilistic estimation and analysis of the following:

- existing failure modes and their effect on the replaceable part's deterioration rate;
- representation of different stressors (i.e. factors that drive the failure mode);
- knowledge and initiation criteria of future failure modes;
- interrelationship between failure modes and their effect on the component deterioration rates;
- the effects of servicing and maintenance on part degradation;
- uncertainty representation and management – meaning the knowledge of the conditions (context) and assumptions underpinning the prognosis. The last point is important given that prognostics deals with the ability to generate insights on damage that is yet to happen.

Conclusion

The adoption of AI technologies, particularly predictive maintenance, is transforming the maritime industry. While the potential benefits of AI in the maritime industry are significant, there are also several challenges and considerations that need to be addressed. These include data privacy and security, regulatory compliance, and the need for skilled personnel to manage and maintain AI systems.

Especially, by leveraging data-driven condition-based maintenance, maritime stakeholders can achieve significant improvements in operational efficiency, safety, and sustainability.

References

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