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*Editorial*

# Intelligent Solutions for Marine Operations

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The maritime sector is undergoing an unprecedented digital transformation driven by rapid advances in artificial intelligence (AI), data analytics, cyber–physical systems, and edge computing [1,2]. Increasingly connected vessels, offshore platforms, and maritime infrastructure are generating vast amounts of operational data that can be exploited to enhance safety, efficiency, sustainability, and decision making [3–5]. At the same time, the growing complexity of maritime operations, together with ambitious decarbonisation targets and the emergence of autonomous shipping, demands intelligent solutions capable of operating reliably in dynamic and often uncertain environments [6]. These developments have accelerated the integration of digital technologies into virtually every aspect of marine operations, from navigation and route planning [7,8] to predictive maintenance [9,10], structural health monitoring [11,12], weather forecasting [13,14], and accident investigation [14,15].

The Special Issue "Intelligent Solutions for Marine Operations" was conceived to showcase recent advances that support this transformation. The contributions collected in this Issue illustrate the breadth of contemporary research while highlighting several common trends. First, machine learning has evolved from a purely predictive tool into an integral component of operational decision-support systems. Second, intelligent algorithms are increasingly combined with physical models, communication technologies, and real-time sensing to enable cyber–physical maritime systems. Third, sustainability objectives are becoming tightly coupled with digitalisation, as AI-driven optimisation contributes directly to fuel savings and emission reduction. Finally, the increasing deployment of intelligent maritime systems has brought new attention to cybersecurity, privacy, and trustworthy AI.

A major theme emerging from this Special Issue is the growing role of AI in supporting maritime decision-making through the analysis of complex and heterogeneous datasets. An article by Escribano Arias et al. (Contribution 1) presents a comprehensive evaluation of retrieval-augmented generation (RAG) systems for maritime accident report analysis using multiple large language models (LLMs). Rather than focusing exclusively on model performance, the authors simultaneously assess cybersecurity vulnerabilities by examining prompt injection attacks based on the OWASP framework. Their study demonstrates that selecting an appropriate LLM requires balancing analytical performance with resilience against adversarial manipulation. By integrating the selected models into a RAG framework for Marine Accident Investigation Branch reports, the work illustrates how generative AI can assist experts in efficiently retrieving safety-critical information while emphasising the importance of secure deployment.

The growing availability of Automatic Identification System (AIS) data has also stimulated research into learning meaningful representations of vessel behaviour. An article by Al-Falouji et al. (Contribution 2) proposes a three-stage representation learning pipeline

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that generates robust trajectory embeddings capable of capturing operational characteristics beyond conventional vessel classifications. Using two years of real-world AIS data, the authors demonstrate that learned behavioural representations outperform manually engineered features and enable improved clustering according to operational context. Such representation learning approaches constitute an important building block for autonomous navigation, vessel traffic services, anomaly detection, and maritime situational awareness, where understanding vessel behaviour is often more informative than considering vessel type alone.

Another dominant research direction represented in this Special Issue concerns predictive modelling of ship and offshore platform dynamics. Accurate short-term prediction of vessel motion is essential for numerous marine operations, including offshore production, helicopter landings, cargo transfer, and navigation under severe environmental conditions.

An article by Jebari et al. (Contribution 3) introduces a hybrid encoder–decoder CNN–LSTM architecture for predicting the motion of a moored floating production storage and offloading (FPSO) platform. By combining convolutional neural networks for spatial wave-field feature extraction with recurrent neural networks for temporal sequence modelling, the proposed framework accurately predicts platform responses under multiple sea states. Particularly noteworthy is the systematic investigation of the optimal spatial wave-field representation, demonstrating that carefully designed input preprocessing remains an essential component of successful deep learning applications.

Similarly, Yu et al. (Contribution 4) develop a real-time prediction framework for a 10,000-TEU container ship by integrating long short-term memory networks with User Datagram Protocol (UDP) communication. The proposed approach enables low-latency transmission and multi-step prediction of ship motions over operationally relevant time horizons. This integration of predictive models with communication protocols reflects an important evolution toward operational cyber–physical systems, where intelligent algorithms become embedded within real-time decision-support architectures rather than functioning as standalone analytical tools.

Structural integrity monitoring represents another critical aspect of intelligent maritime operations. A second article by Jebari et al. (Contribution 5) proposes a two-stage artificial neural network framework for detecting mooring failures in FPSO systems using platform motion data generated from numerical simulations. Separating failure detection from failure localisation substantially improves classification accuracy while reducing ambiguity between individual mooring lines. The study demonstrates how machine learning can support condition monitoring and maintenance planning by enabling near-real-time diagnosis of structural failures without relying exclusively on traditional inspection procedures.

Beyond operational safety, several contributions emphasise the central role of intelligent optimisation in supporting environmentally sustainable shipping. Maritime decarbonisation has become one of the industry's highest priorities, encouraging the development of advanced algorithms capable of simultaneously improving operational efficiency and reducing fuel consumption.

An article by Lee et al. (Contribution 6) presents a novel route optimisation framework that combines transformer-based fuel consumption prediction with reinforcement learning using the Proximal Policy Optimisation algorithm. Rather than optimising solely for minimum distance, the proposed methodology balances fuel efficiency, navigational safety, and operational practicality while accounting for geographical and bathymetric constraints. The reported reductions in fuel consumption across multiple long-distance voyages illustrate the significant potential of AI-driven voyage optimisation to support compliance with increasingly stringent environmental regulations.

Complementing this work, Li et al. (Contribution 7) address a practical limitation frequently encountered during maritime route planning: the availability of high-resolution weather information. The proposed deep super-resolution framework reconstructs detailed weather fields from lower-resolution data using convolutional neural networks, residual learning, and attention mechanisms. By improving the spatial resolution of wave height and wind speed information, the model enhances subsequent route optimisation while reducing unnecessary detours, operational costs, and fuel consumption. This contribution highlights that improvements in data quality can be as influential as advances in optimisation algorithms themselves.

While predictive performance remains an important objective, modern maritime AI systems must also operate under realistic deployment constraints, including limited communication bandwidth, heterogeneous onboard hardware, and increasing concerns regarding data privacy. Addressing these challenges, Kalafatelis et al. (Contribution 8) introduce FLUID, a dynamic federated learning framework designed specifically for predictive maintenance in heterogeneous maritime fleets. By combining client clustering, structured pruning, and knowledge distillation, the proposed framework significantly reduces communication overhead while maintaining high predictive accuracy without centralised data aggregation. Such approaches represent an important step toward scalable edge intelligence for connected vessels, enabling collaborative model training while preserving operational privacy and accommodating differences in onboard computational resources.

The papers collected in this Special Issue reveal several broader trends shaping the future of intelligent maritime systems. First, artificial intelligence is becoming deeply integrated into operational workflows rather than serving merely as an offline analytical tool. Predictive models increasingly support near-real-time decision-making by interacting with communication networks, sensor systems, and operational control frameworks. Second, many studies combine multiple AI paradigms, including deep learning, reinforcement learning, representation learning, federated learning, and large language models, illustrating the growing maturity of interdisciplinary digital engineering approaches. Third, sustainability considerations are consistently embedded within intelligent algorithms, demonstrating that digital transformation and environmental responsibility are complementary rather than competing objectives.

Equally significant is the increasing emphasis on trustworthy AI. As intelligent systems assume greater responsibility for supporting maritime operations, issues such as cybersecurity, robustness, explainability, and privacy become essential design considerations. The inclusion of studies addressing prompt injection attacks, privacy-preserving federated learning, and robust behavioural representations reflects a broader recognition that future maritime AI systems must be not only accurate but also secure, resilient, and deployable under operational constraints.

The contributions further demonstrate the importance of integrating physical understanding with data-driven modelling. Hybrid approaches combining numerical simulations, sensor observations, communication technologies, and machine learning consistently achieve superior operational performance compared with purely data-driven or purely physics-based solutions. Such integration is likely to become increasingly important as digital twins, Internet of Ships technologies, and autonomous marine platforms continue to evolve.

Overall, this Special Issue illustrates the remarkable diversity of intelligent solutions currently emerging across maritime engineering. Although the individual studies address different applications, from accident investigation and vessel behaviour modelling to predictive maintenance, route optimisation, and offshore platform monitoring, they collectively contribute toward a common vision of future maritime operations characterised by connected, adaptive, data-driven, and sustainable systems. Continued collaboration between researchers in artificial intelligence, naval architecture, offshore engineering, oceanography, and maritime operations will be essential for translating these advances into practical industrial applications.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

**List of Contributions:**

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