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Evaluation of the influence of an adaptive instructional system (AIS) on participants' performance in a ship's bridge simulator

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ABSTRACT

Effective ice management training is necessary for safe and efficient operations in sea ice environments, especially for offshore energy industries that experience seasonal incursions of pack and multi-year ice. Traditional training methods in sea ice management are predominantly through classroom courses, simulator-based training, and experiential learning on-the-job. However, traditional forms of training are non-adaptive, have limited scalability, and lack consistency in skill acquisition. This study aims to address this gap by evaluating the effectiveness of an Adaptive Instructional System (AIS) as a potential solution for improving ice management performance in simulation-based training. The AIS integrates a learner model using Decision Trees and an instructor model that incorporates feedback from experienced seafarers to improve skill acquisition in simulated environments. Participants (n = 24) completed three training scenarios and one test scenario in a simulator, focusing on key operational techniques such as pushing, prop wash, and leeway creation. Performance differences were assessed using metrics, such as average change in ice concentration. The findings demonstrated improvements in performance among participants trained with the AIS compared to those without it. These results highlight the potential of an AIS in addressing the limitations of traditional training methods.

KEY WORDS: Adaptive instructional systems; Decision tree; Tailored feedback; Ice management performance

INTRODUCTION

The presence of sea ice and icebergs poses significant challenges to offshore operations. Effective ice management strategies, including breaking, clearing, and deflecting ice, are necessary for protecting infrastructure and maintaining operational efficiency (Wright, 2005; Eik, 2008). As ice management performance is largely influenced by the seafarers operating the vessel, effective training is necessary for a successful operation. Past experience has shown that training is a key factor in developing an effective ice management plan (Keinonen, 2008).

In traditional training methods—including classroom instruction, simulator-based training, and on-the-job learning—seafarers must continuously develop various competencies and skill sets. However, these methods often lack adaptability, making it difficult to fully address trainees' individual learning needs and performance, even with experienced instructors putting in significant effort (Mallam et al., 2019; Betts, 2021).

Additionally, these training methods rely heavily on human instructors, who are both costly and scarce, making it difficult to provide consistent and accessible training at scale. With approximately 1.6 million seafarers worldwide (International Chamber of Shipping, 2019) and a growing demand for highly skilled officers, the need for effective and efficient training has become more pressing (Mallam et al., 2019). This scarcity of qualified instructors poses a significant challenge, emphasizing the need for a more automated and adaptive training system that ensures effective learning for all trainees.

This study evaluates the potential of an AIS to address these limitations by enhancing simulation-based ice management training. AIS enhances adaptability by enabling trainees to refine their ice management skills. It also reduces dependency on human instructors by providing automated, real-time feedback that adapts to individual performance, ensuring a more dynamic and personalized learning experience.

The study builds on prior research by Thistle (2019) and Yazdanpanah (2021), which highlighted the critical role of tailored feedback in improving operational skills in ice management. Building on this foundation, the current study focuses on evaluating AIS's effectiveness in simulated ice management tasks by emphasizing the integration of decision trees for performance diagnostics and incorporating guidance from experienced seafarers. Through operational training scenarios, the study investigates how AIS can bridge the skill gap between novice learners and experienced operators. This study evaluates the effectiveness of AIS in simulated ice management tasks through a series of structured training scenarios. It examines how the integration of decision trees for performance diagnostics and expert-guided interventions influences adaptive learning and enhances maritime training effectiveness. The findings aim to support the development of advanced training programs that better prepare participants to navigate the complexities of real-world ice management operations. To evaluate AIS's impact, two groups of inexperienced participants underwent ice management training using a bridge simulator. The AIS group received personalized, adaptive feedback, while the control group received only standardized, non-personalized feedback. Following training, both groups completed an identical ice management test scenario. As shown in Figure 1, it was hypothesized that the AIS group would outperform the control group, as adaptive, real-time feedback was expected to significantly enhance situational awareness and decision-making skills in ice management operations. The "×" symbols in the boxplot indicate the mean performance values for each group.

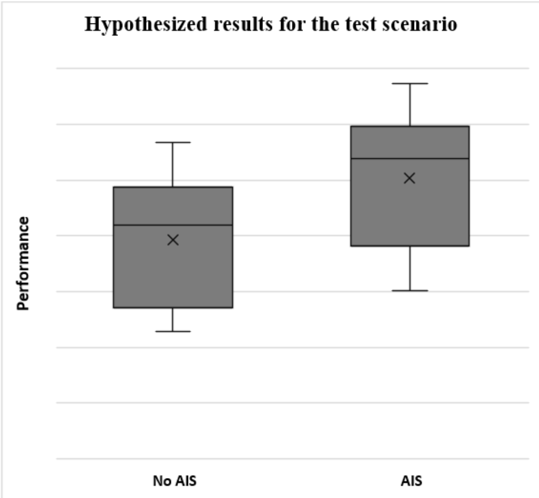


Figure 1. Hypothesized results

BACKGROUND

Effective ice management involves various techniques such as tracking ice movement, clearing pack ice, and deflecting icebergs to safeguard offshore operations (Eik, 2008). Support vessels use standardized maneuvers—including linear, sector, circular, stationary/propeller wash, and pushing techniques—to disperse ice efficiently (Keinonen, 2008). However, predicting pack ice evolution and managing it in advance remains highly complex due to the influence of environmental factors such as wind, current, and ice drift. Operators must be proficient in multiple strategies and capable of adapting to changing conditions in real time (National Snow and Ice Data Center (NSIDC), n.d.).

Ice management training is essential for ensuring safe and efficient offshore operations. where ice poses significant risks to vessels and infrastructure. Proper training equips crews to effectively operate vessels in ice-covered waters, enhancing safety and operational efficiency (Canadian Coast Guard, 2022). To standardize ice management training, the International Maritime Organization (IMO), in collaboration with the Marine Institute’s Centre for Marine Simulation and the Master Mariners of Canada, mandates both basic and advanced training for vessels operating in polar waters (IMO, 2017a; IMO, 2017b). However, formal training alone is often insufficient, as inexperienced cadets frequently rely on experienced operators for practical guidance during ice management operations (Smith et al., 2020).

Simulation-based training has become an important component of ice management education, providing a controlled environment for mariners to develop practical skills. The ISO 35104 standard emphasizes the importance of simulator technology in training, highlighting its role in improving crew qualifications (Hjelmervik et al., 2018). Advanced ship bridge simulators replicate real-world ice interactions, enabling trainees to refine their ice management and maneuvering abilities (Kazantsev et al., 2017).

Simulation-based training has been widely recognized as an effective approach for enhancing ice management skills. Veitch et al. (2019) found that the level of seafarer experience significantly influenced performance in simulator-based training, emphasizing the importance of prior knowledge in achieving proficiency. Similarly, Thistle (2019) demonstrated that structured simulator training plays a crucial role in developing novice operators' competencies, while also providing a framework for estimating the training duration required to reach operational proficiency. Beyond traditional simulation techniques, advancements in decision support systems (DSS) have been explored in the context of ice management training. Yazdanpanah (2021) developed a DSS designed to integrate expert seafarer knowledge, enabling real-time guidance for offshore ice management operations. However, the effectiveness of such systems is not universally guaranteed, as Soper (2022) tested a DSS in ice management training and found that inexperienced trainees did not always achieve statistically significant performance improvements despite following expert-recommended strategies.

Despite its advantages, simulation-based training still faces limitations. Without adaptive mechanisms, trainees may struggle to refine their strategies efficiently, reducing their ability to respond effectively to evolving conditions. To address these challenges, AIS have been introduced as an innovative solution, offering personalized learning experiences tailored to individual performance (Emond, 2021). AISs integrates artificial intelligence and real-time feedback to adjust instructional content, ensuring a more effective and scalable training process. Unlike traditional simulation-based training methods that depend on human instructors for supervision and assessment, AIS provides automated, real-time guidance with minimal intervention (Sottilare, 2018).

By tracing the evolution of ice management training and highlighting the contributions of prior research, this background establishes a foundation for evaluating AIS as an approach to maritime training. The integration of adaptive learning technologies is intended to enhance operators' skills and performance, ensuring they can effectively and safely navigate the complexities of ice management operations.

METHODOLOGY

This study employs a simulation-based experimental design to evaluate the impact of AIS on ice management training. Participants were exposed to three distinct training scenarios—Pushing, Prop Wash, and Leeway—followed by a test scenario. The scenarios were designed to replicate real-world tasks, emphasizing operational ice management technique execution.

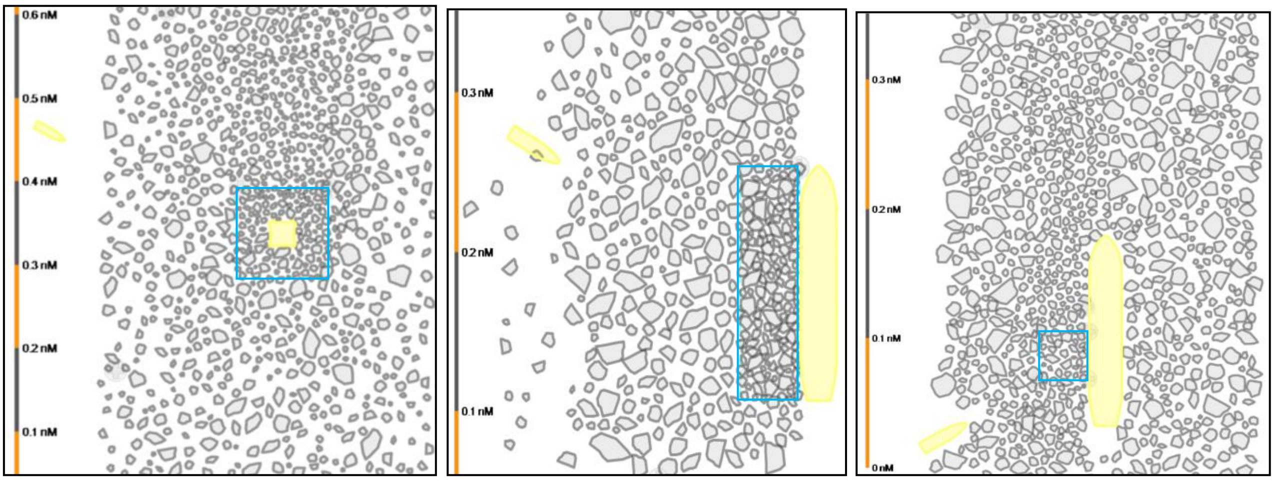
The study involved 24 participants recruited from the university student population. Participants for this experiment were recruited in accordance with a protocol approved by the Interdisciplinary Committee on Ethics in Human Research (ICEHR), under approval number 20241523-EN. All participants were novices with no prior experience in ice management simulators. They were randomly assigned to one of two groups: the AIS Group, which received tailored feedback informed by decision tree diagnostics, and the Control Group, which received standardized feedback without personalization. Participants completed the informed consent form and underwent a pre-screening process to ensure readiness, including assessments for simulator sickness and adherence to pre-experiment guidelines.

A two-level one-factor experimental design was implemented, with the presence or absence of AIS assistance serving as the independent variable. The participants' backgrounds were diversified in terms of academic disciplines, ensuring that the results were representative of novice operators encountering simulation-based ice management for the first time. As illustrated in Figure 2, the participants went through three training scenarios explained as follows:

Pushing Scenario: Participants used the vessel’s bow or side to clear a 75-meter safety zone around an offshore platform. This scenario emphasized precision in vessel positioning and effective ice displacement. Operators had to adapt to shifting ice dynamics while maintaining the safe distance from the platform.

Prop Wash Scenario: Participants employed propeller wake wash to disperse ice alongside a stationary tanker, focusing on understanding the interaction between ice and water dynamics. This scenario tested participants' ability to control the vessel’s propulsion systems effectively to create controlled water currents.

Leeway Scenario: Participants created a lee to prevent drifting ice from encroaching on critical areas, testing their ability to anticipate and manage ice drift patterns. Success in this scenario depended on anticipating ice movement and adjusting vessel position proactively.



Pushing Scenario　Prop Wash Scenario　Leeway Scenario

Figure 2. Training scenario diagrams

Each scenario lasted 15 minutes and featured first-year ice types under different conditions, including differences in ice drift speed and ice concentration. The scenarios aimed to isolate specific operational skills while providing measurable performance metrics. Real-time data logging from the simulator ensured accurate performance tracking for subsequent analysis.

As shown in Figure 3, the final test scenario challenged participants to clear a lifeboat launch area of a moored floating production storage and offloading under seven-tenths ice concentration, drifting at 0.2 knots. Participants were given 30 minutes to apply their learning from their training session, employing any combination of techniques to achieve the objective. This scenario incorporated more complex ice conditions to assess the participants' ability to adapt and prioritize tasks.

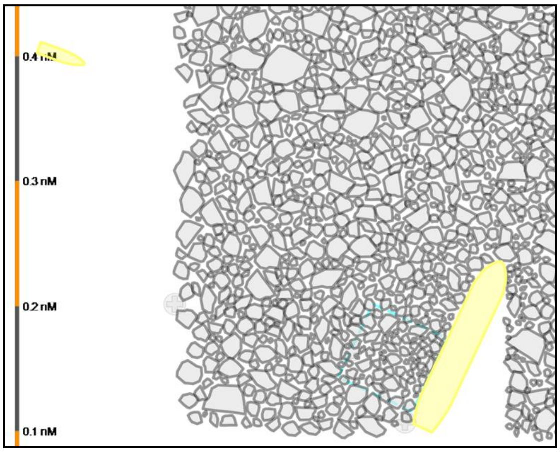


Figure 3. Emergency scenario diagram

The training program followed a structured format consisting of familiarization, scenario execution, and feedback sessions.

Technique Familiarization: Participants reviewed ice management techniques by observing sped-up replay videos of experienced seafarers (Veitch, 2018; Yazdanpanah, 2021) and analyzing instructional screenshots. This approach aimed to develop independent judgment and reinforce learning.

Scenario Execution: Participants applied learned techniques in hands-on scenarios, making real-time decisions. The number of training scenarios varied by group: the No AIS group completed a fixed number of scenarios based on practice time, while the AIS group followed a performance-based approach, with scenario repetition determined by decision tree model diagnostics.

Feedback Sessions: Performance evaluations guided feedback delivery. The AIS group received tailored feedback based on decision tree models, addressing specific weaknesses and suggesting targeted improvements. In contrast, the No AIS group received standardized feedback, primarily comparing their path and end ice concentration performance to experienced seafarers.

During the experiment, several types of data were collected to evaluate participant performance. Simulator log files recorded key vessel parameters, including speed over ground, longitude, latitude, and heading. Additionally, recorded videos from the instructor station captured a bird’s-eye or chart view of the ice management task, enabling the assessment of ice concentrations and performance metrics.

Participant performance videos were analyzed using an image processing Python script, which extracted a bird's-eye view of the ice management zone and tracked changes in ice concentration over time. This analysis involved identifying and classifying pixels as vessel, ice, or open water, as shown in Figure 4. By isolating and evaluating the cleared zones, the method provided insights into participants' operational effectiveness.

To ensure consistency and enable valid comparisons, all participants within each concentration sub-group were assigned identical initial conditions. A baseline was established by measuring changes in ice concentration without any ice clearing, serving as a reference for performance evaluation. By comparing each case to this baseline, key performance metrics were derived for the emergency scenario. These metrics will be described in detail below:

- Average Change in Ice Concentration: This metric evaluated overall ice-clearing effectiveness across the training scenarios. It was determined by calculating the difference in ice concentration within the zone in each scenario relative to the baseline at 30-second intervals throughout the 30-minute scenario. The values from each interval were then averaged. A higher average change in ice concentration indicated superior performance, as it signified greater ice clearance.

- End Change in Ice Concentration: This metric quantified the final ice concentration within the operational area at the conclusion of the scenario. It was computed by measuring the difference in ice concentration within the designated zone at the scenario's end compared to the baseline. A greater end change in ice concentration reflected enhanced performance, as it demonstrated a higher degree of ice clearance.

- Clearing-to-Distance Ratio: This metric assessed the efficiency of ice management relative to vessel movement. It was calculated by dividing the total amount of ice cleared by the distance traveled by the vessel. A higher ratio reflected more effective ice clearing per unit of distance traveled, indicating greater operational efficiency.

RESULTS

This section presents the key findings of the study, including performance metrics for the test scenario, as well as analyses of ice concentration and vessel path. The results revealed significant performance differences between the AIS and No AIS groups. For the emergency ice management scenario, boxplots illustrated in Figure 4 show the differences between the AIS and No AIS groups across three key metrics:

Average Change in Ice Concentration: The AIS group demonstrated a higher average reduction in ice concentration (+1.23 tenths) compared to the No AIS group. This result highlights the AIS group's ability to manage ice more effectively over time, emphasizing their enhanced operational efficiency. The difference was statistically significant ($p = 0.001$), indicating that AIS had a meaningful impact on this performance metric.

End Change in Ice Concentration: The AIS group achieved a significantly higher end change in ice concentration (+2.68 tenths) compared to the No AIS group. This metric reflects the AIS group's superior ability to clear ice by the end of the scenario, underscoring the impact of tailored feedback on improving task outcomes. The observed difference was statistically significant (p = 0.001), confirming the effect of AIS on end change in ice concentration.

Clearing-to-Distance Ratio: The AIS group showed a higher clearing-to-distance ratio (+0.49 tenths), indicating more efficient vessel movements. The smaller variability in this metric for the AIS group also suggests greater consistency in their performance compared to the No AIS group. The improvement in clearing-to-distance ratio was statistically significant (p = 0.001), demonstrating a clear effect of AIS on vessel movement efficiency. Figure 4 presents boxplots that collectively demonstrate how AIS-assisted participants outperformed their counterparts in all key metrics, reflecting the effectiveness of AIS in improving performance during operational scenarios. The "×" symbols in the boxplots represent the mean values for each group, while the "○" symbols denote outliers beyond 1.5 times the interquartile range.

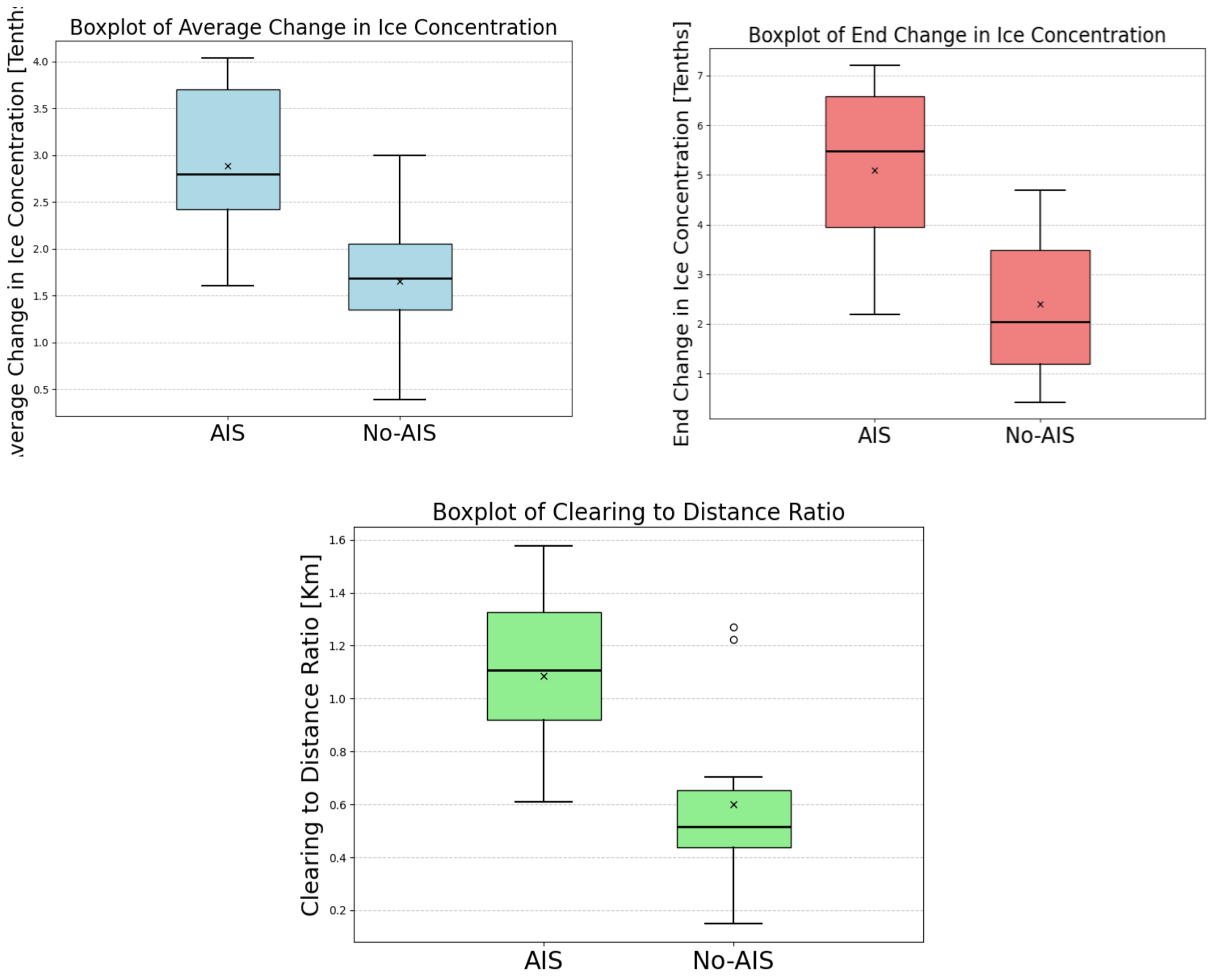


Figure 4. Box plots of three performance metrics for AIS and No AIS groups in test scenario

Time-series plots of ice concentration demonstrated the effectiveness of AIS in facilitating faster and more consistent reductions in ice levels. Figure 5 illustrates the concentration of ice over time during the emergency ice management scenario. The AIS group exhibited a steady and consistent decline in ice concentration, with levels dropping significantly faster than those in the control group. Notably, the AIS group reduced ice concentration by approximately 30% more than the control group by the end of the scenario. In contrast, the control group displayed slower and more variable reductions in ice concentration, indicating less effective management strategies. The graph also incorporates a baseline without ice management, providing a reference point for comparing the effectiveness of active intervention between the two groups.

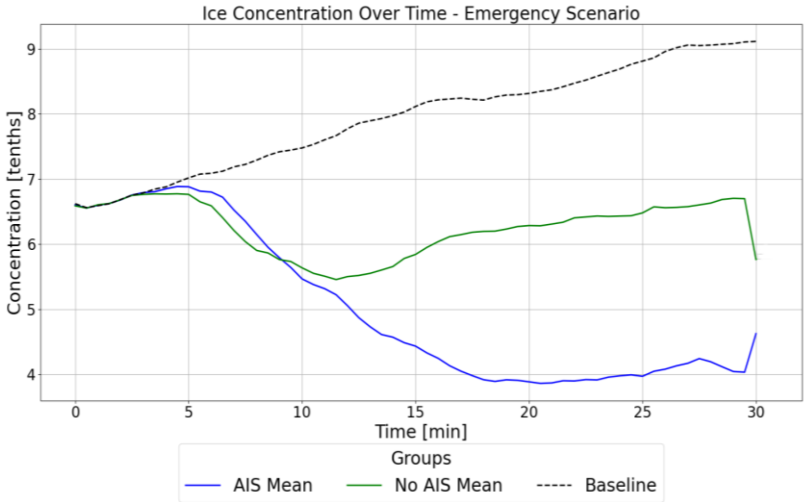


Figure 5. Ice concentration over time plot in emergency ice management scenario

CONCLUSION

This study underscores the transformative potential of AIS in advancing ice management training. The results supported the hypothesis that the AIS group would outperform the No AIS group due to the benefits of adaptive and personalized feedback. AIS-assisted participants demonstrated superior performance across all key metrics, confirming its effectiveness in enhancing ice management capabilities. By addressing the limitations of traditional training methods, AIS provides a scalable and adaptive learning framework that enhances decision-making, operational efficiency, and safety. In conclusion, AIS represents a significant advancement in maritime training, promoting safer and more efficient ice management. Continued development of such systems is essential to meeting the evolving demands of the maritime industry.

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