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THE HUMAN EDGE

Human Factors and the Risks of AI Overreliance in Maritime Defence

CMSN
REPORTS

March 2026

Executive Summary

Artificial intelligence (AI) is increasingly integrated into maritime navigation, surveillance, and decision-support systems to enhance efficiency and accelerate operational tempo. For maritime defence and security organizations, including the Canadian Armed Forces, these technologies support Arctic sovereignty patrols, distributed maritime domain awareness, and coalition interoperability.

While this new technology has much to offer, research on highly automated ferries and maritime autonomous surface ships identifies consistent human factors risks associated with AI overreliance. Automation often shifts operators from active controllers to supervisory monitors, reducing sustained engagement with the operational environment. This shift is linked to three interrelated cognitive risks: degraded situational awareness and vigilance, erosion of manual and cognitive skills, and inappropriate trust in automated systems.

Introduction

Artificial intelligence (AI) and advanced automation are increasingly being integrated into maritime operations to support navigation, collision avoidance, anomaly detection, and decision making under conditions of high information load. In both civilian and state maritime contexts, these technologies are promoted as a means to enhance operational efficiency, reduce human workload, and improve situational awareness (SA) by fusing large volumes of sensor and contextual data into actionable recommendations.[1] For maritime defence and security organizations operating in complex, time-pressured, and information-dense environments, such capabilities are strategically attractive.

At the same time, human factors research shows that increasing reliance on AI-enabled systems can introduce new cognitive and operational risks for human operators. Evidence from highly automated ferries, maritime autonomous surface ships (MASS), and remote or supervisory control settings consistently shows that automation reshapes operator roles, often shifting humans from active controllers to supervisors or "backup" monitors.[2] While this shift may reduce routine task demands, it also alters how operators engage with the operational environment, maintain skills, and calibrate trust in automated systems.

Most empirical evidence on these issues is derived from civilian maritime operations rather than naval or coast guard settings. As a result, research on MASS and highly automated civilian vessels is frequently used to inform understandings of human–automation interaction in maritime operations more broadly.[3] Although defence-specific empirical studies remain limited, recent synthesis work argues that civilian autonomy research offers a defensible basis for identifying cognitive risks that may extend to state maritime contexts, particularly where operational roles involve high levels of automation, remote supervision, or reduced direct sensory engagement with the vessel and environment.[4]

Although existing research identifies numerous human–AI interaction concerns, analyses often remain broad, limiting actionable guidance for defence system design and operational concepts. Recent naval and maritime human–AI teaming roadmaps therefore call for more focused, mechanism-driven approaches that link specific design choices to measurable cognitive outcomes.[5]

Canada's maritime defence and security environment is increasingly shaped by Arctic accessibility, renewed great power competition, long-duration patrol requirements, and coalition interoperability demands. Canada's defence policy, from *Strong, Secure, Engaged*[6] to the renewed vision articulated in *Our North, Strong and Free*,[7] emphasizes strengthening sovereignty, modernizing capabilities, and accelerating decision advantage across maritime approaches. The *Department of National Defence and Canadian Armed Forces Artificial Intelligence Strategy* similarly highlights human–machine teaming and responsible AI integration as central to future operational effectiveness.[8] In this strategic context, AI-enabled navigation, sensor fusion, anomaly detection, and decision-support tools are positioned as enablers of accelerated operational tempo and distributed decision advantage.

Yet the same automation introduces human performance risks that become more consequential in contested, degraded, or cyber-manipulated environments — conditions that increasingly define the operational reality of Canadian maritime defence. In environments where adversaries employ electronic warfare, Global Navigation Satellite System (GNSS) spoofing, or information manipulation, the quality of human–AI interaction determines whether deception is detected and managed. Under such conditions, automation shifts from an efficiency multiplier to a potential vulnerability if vigilance, cross-verification, and calibrated trust are not preserved.

The Arctic exemplifies this tension. As a strategically consequential operating space characterized by sparse infrastructure, environmental volatility, and heightened geopolitical attention, it amplifies the consequences of degraded navigation and delayed anomaly detection. Rather than simply facilitating faster decision making, AI-enabled systems in the Arctic become critical mediators of how information is perceived, interpreted, and acted upon.

As Canada accelerates AI-enabled maritime capability development in support of Arctic sovereignty, distributed sensing, and decision advantage, the human–AI interface becomes a strategic control point. Evidence from maritime autonomy research indicates that shifts toward supervisory automation can degrade situational awareness, erode skills, and destabilize trust in ways that remain largely invisible during routine operations but become critical under degraded or adversarial conditions. This paper draws on converging evidence from ferry field studies, simulator research, and systematic reviews to identify cognitive mechanisms that may drive AI overreliance in maritime defence contexts and develops policy-relevant recommendations to preserve operator resilience under contested conditions. The following operational vignette illustrates how these mechanisms may unfold in a Canadian maritime defence context.

Operational Vignette: GNSS Manipulation, Fused Displays, and Delayed Verification

Between 2017 and 2019, multiple commercial vessels operating in the Black Sea reported Global Positioning System (GPS) interference and anomalous GNSS positioning, including intermittent, absent, or incorrect signals, as documented in U.S. Maritime Administration Advisory 2017–007.[9] Although radar and visual references remained available, integrated bridge displays continued to present internally coherent track information, delaying the recognition of positional anomalies.

Marine Accident Investigation Branch investigations into Electronic Chart Display and Information System (ECDIS)–related groundings document instances in which crews did not independently verify electronic navigation data, even when discrepancies were detectable.[10] These cases illustrate a pattern observed across multiple maritime investigations: when electronic inputs are internally coherent and automation has been reliable in routine operations, operators may delay active verification.

Although these incidents occurred in civilian contexts, they demonstrate cognitive mechanisms that are not sector specific. The following vignette extrapolates these mechanisms to a Canadian maritime defence scenario to illustrate how automation, supervisory monitoring, and miscalibrated trust may interact under contested Arctic conditions.

Phase 1: Routine operation (automation as efficiency multiplier). A Canadian sovereignty patrol operates in Arctic waters under low visibility and high workload, relying on AI-enabled sensor fusion (GNSS, automatic identification system [AIS], radar, environmental data) to support track projections and anomaly alerts.

Phase 2: Subtle manipulation (automation becomes a vulnerability). Spoofed positioning inputs are fused into the system's track picture without triggering alarms, producing a coherent – but corrupted – display state.

Phase 3: Supervisory mode (reduced active sampling and vigilance decrement). Bridge personnel positioned primarily as monitors defer cross-checking because the fused display appears internally consistent and the system has been reliable in routine operations.

Phase 4: Compressed recovery window (Arctic penalties). In Arctic waters, sparse charting, limited infrastructure, and degraded electromagnetic conditions reduce redundancy; delayed manual verification compresses safety margins and increases operational risk.

Phase 5: Mission assurance consequence (trust calibration and degraded-mode readiness become decisive). Under contested conditions, the human operator becomes the final anomaly-detection mechanism when corrupted inputs are fused into a coherent system picture; mission assurance therefore depends on calibrated trust, sustained vigilance, and degraded-mode readiness – not only technical performance.

The vignette illustrates how documented patterns of automation reliance and verification delay can interact under contested conditions, reinforcing the need to examine situational awareness, skill retention, and trust calibration as interdependent risk mechanisms.

Analytical Scope and Focus

To address these gaps, this analysis deliberately narrows its focus to three interrelated cognitive outcomes that are consistently identified across empirical, qualitative, and review-based maritime autonomy studies:

1. Situational awareness and vigilance, particularly under prolonged supervisory monitoring conditions;
2. Skill retention and cognitive atrophy, including reduced confidence and preparedness for degraded or non-automated modes; and
3. Trust calibration, encompassing both overreliance and under-reliance on AI-enabled systems.

These outcomes are examined together rather than in isolation, as evidence shows that automation-driven shifts in operator roles tend to influence situational awareness, skill retention, and trust in interconnected ways.

Relevance to Maritime Defence and Security Operations

Within this context, findings from automated ferry and MASS research highlight several mechanisms with direct implications for maritime defence and security operations. Naval bridge teams, Arctic patrol vessels, and shore-based maritime domain awareness centres increasingly rely on automated navigation aids, sensor-fusion systems, and AI-enabled decision-support tools that perform functions similar – though not identical – to those examined in civilian contexts.[11] As Canada modernizes its maritime capabilities to strengthen sovereignty, accelerate decision advantage, and enhance coalition interoperability,[12] these systems are expected to play an expanding role in operational decision making.

Defence operations introduce additional stressors not typically present in civilian settings, including time pressure, ambiguous threat cues, degraded communications, and the possibility of deliberate adversarial interference. Operations in Arctic waters or contested electromagnetic environments may involve reduced satellite availability, sensor disruption, or information manipulation. Under these conditions, the cognitive vulnerabilities identified in automation research – such as automation bias, vigilance decrement, skill fade, and miscalibrated trust – may be amplified.[13]

These vulnerabilities extend beyond reduced efficiency. In maritime defence operations, delayed intervention, degraded situational awareness, or inappropriate reliance on automation can affect sovereignty patrols, maritime domain awareness accuracy, coalition coordination, and force protection. Where Canada's defence posture emphasizes distributed sensing, accelerated decision cycles, and integrated information sharing, the integrity of human–AI interaction becomes directly linked to operational assurance.

Accordingly, this analysis does not generalize civilian findings uncritically to military operations. Rather, it draws on established human factors evidence to identify credible cognitive risk pathways associated with AI overreliance in maritime defence settings and to develop operationally grounded recommendations aligned with Canada's modernization and sovereignty objectives.

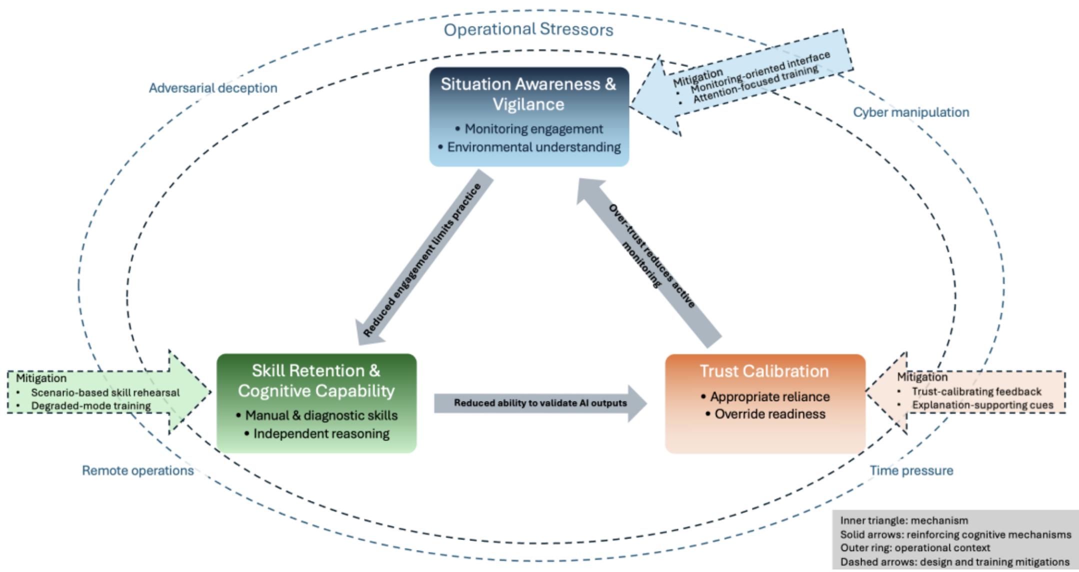
Conceptual Framework

Figure 1 presents the Situational awareness–Skill–Trust (SA–Skill–Trust) framework, which synthesizes evidence from maritime autonomy research to illustrate how AI-enabled systems reshape operator roles and cognition. The framework highlights a reinforcing relationship between operator engagement, skill maintenance, and trust in automation under AI-enabled maritime operations.

The framework does not assert validated causal relationships or quantified effect sizes. Instead, it integrates converging qualitative, empirical, and review evidence to highlight cognitive mechanisms that warrant attention in maritime defence and security contexts. The sections that follow examine evidence related to situational awareness and vigilance, skill retention, and trust calibration in turn, before considering their implications for AI-enabled maritime operations.

Figure 1.

A Conceptual Framework of the SA–Skill–Trust Loop in AI-Enabled Maritime Operations



Note: Conceptual framework depicting the Situational awareness–Skill–Trust (SA–Skill–Trust) loop in AI-enabled maritime operations. AI-supported navigation, anomaly detection, and decision-support systems reconfigure operator roles from active control to supervisory monitoring. This role shift is linked to the degradation of situational awareness and vigilance, erosion of cognitive and manual skills, and miscalibration of trust in automation. Miscalibrated trust, in turn, reinforces reliance on AI, strengthening the loop. Transparency features, training and operational concepts, and broader operational context act as moderating influences on these relationships. The framework synthesizes empirical, qualitative, and review evidence from maritime autonomy and highly automated navigation studies.[14]

A consistent finding across studies of highly automated maritime systems is that AI-enabled navigation and decision support alter the cognitive conditions under which situational awareness (SA) is formed and maintained. Rather than continuously perceiving, interpreting, and projecting vessel and traffic states, operators are increasingly positioned as supervisors of automation, intervening primarily when systems generate alerts or encounter uncertainty.[15]

Empirical fieldwork in automated ferry operations shows that this role shift affects how operators engage with their environments. Veitch et al., based on interviews with ferry operators using highly automated navigation systems, report that operators experienced reduced immersion in the navigational task and described their work as increasingly characterized by passive monitoring. Operators noted long periods of low engagement punctuated by moments requiring rapid intervention, a pattern that several participants associated with difficulty "staying mentally in the situation."[16] These accounts align with classic vigilance research but are grounded here in real maritime operations rather than laboratory analogues.

Veitch et al. also document a mismatch between system designers' assumptions and operators' lived experience. Designers described navigators as remaining "in the loop" because automation could be overridden at any time; operators, by contrast, reported that the automation's reliability and dominance in routine tasks made active engagement difficult to sustain.[17] While this study does not directly measure SA quantitatively, it provides qualitative evidence that supervisory control alters the information sampling and cognitive rehearsal processes that underpin SA.

Situational awareness and Vigilance Under AI-Enabled Maritime Operations

Vigilance Decrement in Prolonged Monitoring Tasks

Vigilance decrement, understood here as the declining ability to detect infrequent or unexpected events during sustained monitoring, is a central concern in supervisory control contexts. Evidence from the maritime autonomy literature shows that AI–supported monitoring tasks create conditions conducive to vigilance loss.

In the highly automated ferry context, Veitch et al. report that operators experienced boredom and reduced alertness during routine voyages in which automation handled most navigational decisions. Operators explicitly linked these experiences to concerns about delayed reactions if automation failed or if unexpected traffic behaviour emerged. Importantly, these findings are based on operational systems in daily use rather than experimental prototypes, strengthening their relevance for real-world maritime operations.[18]

Palbar Misas et al. provide complementary evidence from simulator-based and tabletop studies involving experienced navigators. Using full-bridge simulators, questionnaires, and scenario discussions, the authors examined perceived situational awareness across varying levels of automation and remoteness. Participants consistently reported lower perceived SA in remote and highly automated operational modes compared to traditional onboard navigation. The authors attribute this reduction to diminished physical cues, reliance on digital representations of the environment, and a reduced need for continuous active decision making. While Palbar Misas et al. rely partly on self-reported measures rather than objective SA metrics, the convergence of simulator, questionnaire, and discussion data supports the conclusion that operators themselves experience vigilance and awareness challenges under increased automation.[19]

Situational awareness, Automation Reliability, and Intervention Readiness

SA degradation in AI-enabled systems has direct implications for intervention readiness. Evidence across multiple studies suggests that when automation performs reliably under normal conditions, operators may struggle to quickly re-establish high-quality situational awareness when anomalies occur.

Veitch et al. document that ferry operators often relied on automation to such an extent that re-engaging with the navigational situation during abnormal events required significant cognitive effort. Operators described needing time to "rebuild the picture" of traffic and vessel states before acting, particularly after extended periods of monitoring. This finding aligns with concerns that supervisory roles reduce opportunities for continuous SA updating, making rapid transitions to manual control more difficult.[20]

Similarly, Palbar Misas et al. report that navigators expressed concern about their ability to respond effectively during cyber incidents or system degradations in remote operations. Participants noted that reduced SA in automated modes could delay recognition of problems and slow the formulation of appropriate responses. Although the study does not experimentally measure intervention latency, it provides practitioner testimony linking automation, reduced SA, and perceived operational risk.[21]

Implications for Maritime Defence and Security Operations: Situational awareness

These risks are particularly consequential for defence and security operations, where intervention often occurs under time pressure and uncertainty. Naval bridge teams and shore-based control centres increasingly rely on automated navigation aids, sensor fusion, and decision-support systems intended to reduce workload and improve efficiency.[22] Evidence from maritime autonomy research indicates that supervisory monitoring roles can undermine situational awareness and vigilance, especially during low-event-rate operations.

For defence and security contexts, the consequences of delayed anomaly detection or intervention may extend beyond those typically encountered in civilian shipping, affecting safety, security, and mission effectiveness. Although defence-specific empirical measurements of SA degradation under AI-enabled systems remain limited, consistent findings from ferry field studies[23] and simulator-based maritime autonomy research[24] support the plausibility of these risks in state maritime operations.

Taken together, this body of evidence indicates that AI-enabled maritime operations can degrade situational awareness and vigilance through role reconfiguration toward supervisory monitoring. Reduced active engagement, diminished environmental immersion, and prolonged periods of low task demand are linked to vigilance loss and difficulty re-establishing SA during abnormal events. These mechanisms constitute the first component of the SA–Skill–Trust loop (Figure 1) and provide the basis for examining how sustained reductions in engagement contribute to skill retention challenges over time. For the Canadian Armed Forces (CAF), these findings suggest that AI-enabled maritime capability development must treat vigilance and intervention readiness as operational design variables rather than incidental by-products of automation adoption.

Skill Retention and the Effects of Supervisory Automation

Supervisory Oversight: Implications for Skill Maintenance

A recurring concern in the maritime autonomy literature is that AI-enabled navigation and decision support reduce opportunities for operators to practise and maintain both manual and cognitive skills. When automation assumes responsibility for routine navigation and rule application, operators spend less time actively planning manoeuvres, anticipating traffic evolution, and resolving ambiguity, activities that are central to maintaining navigational competence and adaptive problem solving.

Field-based qualitative evidence from highly automated ferry operations illustrates this shift clearly. Veitch et al. report that operators experienced a progressive reduction in hands-on navigational involvement as automation handled most routine tasks. Participants described fewer opportunities to make decisions independently and expressed concern that their skills were "rusting" due to limited practice. Importantly, these concerns extended beyond manual control to include confidence in judgment and readiness to act during abnormal situations.[25]

Complementary insights are provided by Veitch et al., who document a discrepancy between designers' expectations and operators' lived experience. While designers viewed automation as enabling skilled human oversight, operators reported that reliable automation reduced both the need and the opportunity to remain continuously engaged with the navigational task. This mismatch suggests that skill erosion may emerge not from a lack of initial competence, but from system designs and operational practices that progressively deprioritize active skill use.[26]

Cognitive Atrophy and Degraded-Mode Readiness

Evidence from maritime autonomy research indicates that cognitive skills such as mental model maintenance, anticipatory reasoning, and degraded-mode problem solving are particularly vulnerable under prolonged supervisory control. Lützhöft et al., drawing on ethnographic workshops with maritime experts, identify a future risk in which operators supervising autonomous vessels lose familiarity with the detailed mechanics of navigation and ship handling. Participants highlighted concerns about long-term competence, certification, and readiness to intervene when automation fails or behaves unexpectedly.[27]

Empirical support for these concerns is provided by Palbar Misas et al., who examined navigator experiences across varying degrees of automation and remoteness using simulator exercises, tabletop scenarios, and questionnaires. Participants consistently reported lower confidence in their ability to manage degraded or non-automated modes in highly automated or remote operations. The authors associate this reduced confidence with diminished opportunities for skill rehearsal and increased reliance on automated system outputs during routine operations.[28]

Although Palbar Misas et al. do not provide objective measures of skill degradation, their triangulated methodology, combining simulator exposure with reflective assessment, supports the interpretation that automation influences not only perceived competence but also operators' preparedness to respond under non-nominal conditions, including cyber incidents and system failures.[29]

Decision-Making Skills and the Erosion of Cognitive Rehearsal

Systematic reviews reinforce the link between automation and changes in decision-making skill development. Lynch et al., in a systematic review of decision making in MASS, identify reduced human engagement and altered decision authority as recurring themes across the literature. The authors note that when operators are positioned primarily as supervisors, opportunities for continuous decision making and cognitive rehearsal diminish, increasing reliance on automation-generated cues and recommendations.[30]

Lynch et al. extend this work using the Schema World Action Research Method to examine how operators reason and act in remote MASS control scenarios. Their findings indicate that reduced interaction with the environment constrains the development and maintenance of robust cognitive schemas, particularly those required to manage unexpected or ambiguous situations. The authors attribute this effect to limited feedback, abstraction of system state, and reduced experiential learning under remote supervision.[31]

Although these studies focus on civilian MASS contexts, the underlying mechanisms are relevant to any maritime operation that relies heavily on automation and remote or supervisory control. Consistent patterns are reported in a broader systematic review of human–machine cooperation in MASS, which identifies reduced operator engagement, constrained decision authority, and increased dependence on automated cues as recurring factors influencing human performance under high levels of autonomy.[32]

Interaction Between Skill Retention and Situational awareness

Evidence from maritime autonomy research indicates that skill retention and situational awareness are closely linked. The reduced use of manual and cognitive skills limits operators' ability to independently interpret system information, which in turn undermines situational awareness and increases reliance on automation.

Veitch et al. report that operators who felt less confident in their own skills were more likely to defer to automated systems, even when they sensed that something was "not quite right."[33] A similar pattern is described by Palbar Misas et al., who found that reduced confidence in manual and cognitive skills coincided with lower perceived situational awareness in automated and remote operational modes.[34] Together, these findings suggest that skill erosion influences not only intervention capability but also how operators perceive, interpret, and monitor unfolding situations.

This interaction forms a central component of the Situational awareness–Skill–Trust loop illustrated in Figure 1. As skill retention declines, operators' capacity to verify and contextualize AI outputs is reduced, increasing the likelihood of overreliance or delayed intervention. These effects are likely to be magnified under conditions of time pressure or degraded system performance.

Implications for Maritime Defence and Security Operations: Skill Retention

Evidence on skill retention highlights risks that are particularly consequential for maritime defence and security operations. Naval and coast guard personnel are expected to operate effectively across a wide range of conditions, including degraded sensor performance, contested environments, and system failures. Available evidence suggests that prolonged reliance on AI-enabled systems without deliberate opportunities for skill maintenance may undermine this readiness.

Sturtevant et al. describe AI-based navigation decision aids as tools intended to support, rather than replace, human judgment.[35] However, the studies reviewed here suggest that without careful attention to training and operational concepts, even well-intentioned decision-support systems can reduce opportunities for skill rehearsal. This risk is compounded in defence contexts, where operators may be required to intervene rapidly under conditions that differ substantially from routine operations.

AI-enabled maritime operations can contribute to skill fade and cognitive atrophy by reducing active engagement, limiting decision-making practice, and constraining experiential learning. These effects are documented through field interviews with ferry operators,[36] ethnographic and expert analyses of future autonomy,[37] simulator-based studies with experienced navigators,[38] and systematic and methodological reviews of MASS decision making.[39]

The consistency of these findings across methods and contexts supports the inclusion of skill retention as a core component of the SA–Skill–Trust loop. Together with situational awareness, changes in skill confidence shape how operators rely on, interpret, and interact with AI-enabled systems.

Trust Calibration and Transparency in AI-Enabled Maritime Operations

Trust Calibration and Reliance Dynamics

Trust calibration, understood as operators' ability to rely on AI appropriately without systematic over- or under-reliance, is consistently identified in the literature as a key mechanism linking situational awareness and skill retention to operational performance. In AI-enabled maritime systems, trust functions as a dynamic state shaped by system reliability, transparency, operator experience, and the availability of cues that support independent verification.

Systematic reviews of human–AI interaction in maritime autonomy report that both over-trust – commonly described as automation bias – and under-trust – reflected in disuse or delayed reliance – occur when operators are unable to adequately interpret or evaluate automated system behaviour.[40] Rather than asserting uniform effects, these reviews document recurring patterns across diverse MASS and highly automated navigation contexts, indicating that trust calibration is strongly influenced by system design features and operational conditions.

Over-Trust, Reduced Verification, and Automation Bias

Research on maritime autonomy shows that over-trust becomes more likely when operators' ability to independently assess the operational situation is reduced.[41] Under supervisory monitoring conditions, reduced active engagement and the erosion of manual and cognitive skills limit operators' capacity to cross-check AI outputs against their own understandings of the environment, increasing reliance on automated recommendations.

Palbar Misas et al. provide empirical support for this relationship through simulator-based and tabletop studies involving experienced navigators. Participants reported greater reliance on automated and remote systems when operating in highly automated modes, particularly in the absence of physical cues and direct vessel feedback. Reduced perceived situational awareness and lower confidence in manual skills coincided with the increased acceptance of system outputs, even when participants expressed concern about cyber incidents or anomalous system behaviour. Although the study does not directly quantify automation bias, the convergence of self-reported trust, situational awareness, and confidence measures supports the interpretation that over-trust can emerge when independent situation assessment is limited.[42]

Qualitative findings from Veitch et al. further reinforce this pattern. Ferry operators described deferring to automation during routine operations because of its consistent reliability, which reduced the perceived need to actively question system behaviour. Several operators noted that this reliance made it more difficult to detect subtle deviations or emerging problems, particularly following extended periods of monitoring.[43] Together, these accounts indicate that over-trust reflects a behavioural adaptation to automation-dominated work practices, rather than a simple attitudinal bias.

Under-Trust and Brittle Reliance

Research also documents the risks associated with under-trust in AI-enabled maritime systems. Systematic reviews report that early false alarms, poorly explained system outputs, or opaque decision logic can lead operators to discount automation, increasing workload and potentially delaying effective intervention when automated support would be beneficial.[44]

In their review of AI decision transparency for autonomous shipping, Madsen and Kim identify multiple cases in which insufficient, poorly timed, or cognitively misaligned explanations reduced operator confidence in automated collision-avoidance and decision-support systems. The authors emphasize that transparency mechanisms are not inherently beneficial. When explanations overwhelm operators or fail to align with task demands, they can destabilize trust and encourage selective use, workarounds, or disuse of automation.[45]

This pattern is supported by simulator-based research from Madsen et al., who demonstrate that transparency features can influence operator understanding and the timing of intervention in autonomous ship scenarios. Their findings indicate that transparency affects not only whether operators trust automation but also how consistently and appropriately they rely on it.[46] Although the study is conducted in civilian MASS contexts, it provides empirical evidence that trust calibration is sensitive to interface design choices and explanation strategies.

Transparency as a Trust-Calibration Tool

Across the maritime autonomy literature, transparency is frequently identified as a key mechanism for trust calibration, albeit with important qualifications. Transparency supports appropriate reliance when it facilitates operator sensemaking and verification, rather than simply exposing internal system processes or technical detail.

Madsen and Kim categorize transparency approaches according to information content, such as rationale and uncertainty, visualization, and interaction timing. Their synthesis indicates that layered and context-dependent transparency, in which the type and depth of information adapt to operational demands, is more likely to support appropriate reliance than static or uniform explanations. This conclusion is drawn from patterns observed across multiple autonomous shipping studies rather than from a single experimental result, and it should be interpreted as indicative rather than definitive.[47]

Zhang and Xu extend this line of reasoning by proposing adaptive explainability mechanisms for MASS. Drawing on a broad body of prior research, they argue that transparency should be tailored to operator workload, task phase, and risk level, particularly during handovers and emergency situations.[48] Although their contribution is conceptual and does not introduce new empirical data, it aligns closely with empirical findings elsewhere in the literature linking transparency design to trust calibration and intervention readiness.

Interaction Between Trust, Situational awareness, and Skill

Evidence across maritime autonomy studies indicates that trust calibration does not operate independently but is closely intertwined with situational awareness and skill retention. Changes in any one of these elements appear to influence the others, shaping how operators engage with AI-enabled systems.

Palbar Misas et al. explicitly link trust to both perceived situational awareness and confidence in operator skills. Participants who felt less capable of independently interpreting system information reported greater reliance on automated outputs, whereas those with higher confidence in their own judgment described more active monitoring and verification behaviours. These findings indicate that trust calibration is mediated, in part, by operators' perceived competence and their understanding of the operational situation.[49]

Qualitative findings from Veitch et al. reinforce this interaction. Operators reported increased reliance on automation as opportunities for skill use diminished over time. Together, these patterns align with the Situational awareness–Skill–Trust loop illustrated in Figure 1, in which reduced engagement contributes to skill erosion, limits independent verification, and promotes greater reliance on automation, further reinforcing supervisory monitoring roles.[50]

Implications for Maritime Defence and Security Operations: Trust Calibration

For maritime defence and security organizations, miscalibrated trust presents distinct operational risks. Defence operations may involve degraded sensor performance, adversarial interference, or unexpected system behaviour, conditions under which over-trust can delay anomaly detection and under-trust can increase workload and slow effective response.

Sturtevant et al. emphasize that AI-based decision aids in naval navigation are intended to support, rather than replace, human judgment. Without deliberate attention to transparency, training, and operational concepts, AI-enabled systems may nonetheless foster reliance patterns that undermine this intent. Relationships observed between automation, situational awareness, and trust in maritime autonomy research suggest that similar trust-calibration challenges are plausible in naval and coast guard operations.[51]

Across studies, trust calibration emerges as a critical factor shaping AI overreliance in maritime contexts. Over-trust tends to arise when reductions in situational awareness and skill confidence limit operators' ability to verify AI outputs, whereas under-trust is more likely when systems are opaque or provide explanations that are poorly aligned with task demands. Transparency, when designed to support operator sensemaking and independent verification, plays a central role in stabilizing trust. Together, these dynamics complete the Situational awareness–Skill–Trust loop and clarify how overreliance can develop through routine operational practice.

Implications and Recommendations for Maritime Defence and Security Operations

Implications of the Situational awareness–Skill–Trust Loop

The synthesis presented here shows that AI-enabled maritime systems can unintentionally generate reinforcing cognitive risks through role reconfiguration, reduced operator engagement, and unstable trust. The mechanisms identified across the literature, including supervisory monitoring, reduced sensory immersion, diminished cognitive rehearsal, and increased reliance on abstracted system representations, are directly applicable to maritime defence and security contexts. Systematic review evidence further indicates that human–AI interaction challenges in autonomous ship systems consistently centre on supervisory control, evolving operator roles, and safety-critical reliance dynamics, underscoring that these concerns are not isolated findings but rather recurring patterns across the field.[52]

Naval bridge teams and shore-based control centres increasingly depend on automated navigation aids, sensor fusion, and decision-support tools to manage information volume and operational tempo.[53] When these systems reposition operators into extended monitoring roles, studies consistently report degradation in situational awareness and vigilance,[54] the gradual erosion of skill retention,[55] and an increased risk of trust miscalibration.[56]

In maritime defence and security operations, these risks carry particular weight. Intervention often occurs under time pressure and uncertainty, and degraded or contested conditions may require rapid transitions away from automated modes. Although defence-specific quantitative estimates remain limited, the convergence of findings across maritime autonomy research indicates that overlooking these mechanisms during AI adoption could compromise operational resilience. For organizations pursuing distributed maritime domain awareness and expanded Northern presence, the cognitive resilience of operators supervising AI-enabled sensor fusion systems becomes a strategic capability variable. Under contested electromagnetic conditions, the human operator may serve as the final anomaly-detection mechanism when corrupted inputs are fused into internally coherent system displays. Preserving calibrated trust, vigilance, and degraded-mode readiness therefore directly supports mission assurance in distributed and Arctic operations. For the CAF, this linkage between cognitive resilience and AI-enabled supervision aligns directly with current defence priorities emphasizing decision advantage, Arctic sovereignty, and sustained operational readiness under contested conditions.

Design Implications: Supporting Active Engagement and Verification

Across maritime autonomy research, system design choices are shown to play a central role in shaping operator engagement and trust behaviour. Multiple studies highlight that transparency and interface design are most effective when they support operator verification and sensemaking, rather than simply presenting automated outputs for acceptance. Drawing on Madsen and Kim's synthesis of AI decision transparency research,[57] together with supporting simulator-based findings,[58] several design implications are particularly relevant for defence and security applications.

Transparency is most effective when it is layered and context sensitive. AI-enabled systems benefit from providing different levels of explanatory detail depending on the task phase, workload, and operational risk. High-level summaries may be sufficient during routine operations, while access to deeper rationale, uncertainty information, and system reasoning becomes critical during anomalies, handovers, or degraded conditions. Interface design should also communicate the uncertainty and confidence associated with AI recommendations. Explicit cues regarding robustness or confidence support operator judgment and help discourage the uncritical acceptance of automated outputs, particularly when system performance may be degraded or contested. Equally important is preserving operators' ability to independently cross-check automated recommendations. Maintaining access to underlying sensor data, alternative visualizations, and non-aggregated information enables operators to sustain their own situation assessment and supports active engagement rather than passive monitoring.

Zhang and Xu propose adaptive explainability mechanisms for MASS that align closely with these principles.[59] Although their contribution is conceptual, it is consistent with empirical findings demonstrating that transparency design influences trust calibration and the timing of operator intervention.[60] For the CAF, embedding such layered and adaptive transparency mechanisms into AI-enabled maritime systems would directly support defence modernization efforts by preserving human oversight, strengthening anomaly detection capacity, and safeguarding mission assurance in sovereignty patrols and coalition operations.

Training and Operational Concepts (CONOPS): Preserving Skills and Vigilance

Evidence from ferry operations, simulator studies, and ethnographic analyses indicates that both training and operational concepts – meaning how roles, responsibilities, and modes of operation are defined in practice – play a central role in moderating automation-related skill degradation and vigilance loss. Lützhöft et al.,[61] Palbar Misas et al.,[62] and systematic review evidence from autonomous shipping research[63] emphasize that shifts in operator roles under increasing autonomy require corresponding changes in training approaches and operational practice.

One implication is the need for the deliberate inclusion of "AI-off" and degraded-mode training. Regular exposure to navigation and decision making without AI assistance supports the maintenance of the manual and cognitive skills required for effective intervention when automated systems fail or behave unexpectedly. Training also benefits from emphasizing rare but high-consequence scenarios. Given the vigilance challenges associated with prolonged monitoring roles,[64] scenario-based exercises that focus on infrequent anomalies, system degradations, or unexpected events can reinforce readiness and reduce reliance on automation during critical moments. Where operationally feasible, rotation between active control and supervisory roles may further support engagement and skill retention. Alternating responsibilities can counter prolonged periods of passive monitoring and sustain opportunities for cognitive rehearsal.

Taken together, these training and operational considerations align with operator concerns documented in automated ferry studies[65] and with navigators' expressed need for new competencies to manage automated and remote operations effectively.[66] For the CAF, integrating degraded-mode proficiency, anomaly-focused scenario training, and rotational supervision models into maritime concepts of operations (CONOPSs) would directly support sustained readiness and decision advantage in Arctic sovereignty patrols and distributed coalition operations.

Evaluation Implications: Measuring What Matters

A recurring limitation identified across the literature is the lack of systematic evaluation of cognitive outcomes during AI adoption. Reviews of decision making and transparency in MASS research note that many studies prioritize system capability and performance while giving limited attention to operator cognition and behaviour.[67] For maritime defence and security organizations, this gap points to the need for more explicit evaluation of human-centred outcomes alongside technical performance.

Evaluation efforts should address situational awareness and vigilance. Task-appropriate probes, simulator-based scenarios, and structured self-assessment can each contribute insight, provided their limitations are recognized and results are interpreted cautiously. Assessment should extend beyond manual control performance to include skill retention at the cognitive level. Measures should capture anticipatory reasoning, problem solving under degraded conditions, and readiness to intervene when automation fails or behaves unexpectedly. Evaluation should also consider trust calibration in behavioural terms. Patterns of reliance, verification behaviour, and intervention timing provide more informative indicators of trust calibration than attitudinal trust scales alone.

The existing literature does not offer standardized metrics tailored to defence contexts. As a result, the evaluation of these cognitive outcomes should be treated as an area for continued methodological development rather than immediate standardization. For the CAF, developing defence-relevant cognitive evaluation frameworks for AI-enabled maritime systems would directly support responsible AI integration, operational legitimacy, and sustained mission assurance in contested and coalition maritime environments.

Policy and Implementation Recommendations for DND/CAF

The preceding analysis identifies specific cognitive risk mechanisms that require deliberate policy, procurement, training, and evaluation responses within the Department of National Defence (DND)/CAF. For the CAF, these risks are not merely technical considerations but operational variables that directly influence mission assurance in sovereignty patrols, Arctic operations, and coalition maritime environments.

These recommendations are aligned with Canada's defence modernization objectives as articulated in *Strong, Secure, Engaged* and *Our North, Strong and Free*, particularly the emphasis on decision advantage, Arctic sovereignty, and responsible AI integration. They are grounded in the Situational awareness–Skill–Trust loop and the convergent evidence previously synthesized in this paper. In light of these operational risks and modernization priorities, the following policy-level measures are recommended.

First, cognitive risk assessment should be embedded into AI-enabled maritime procurement processes. System evaluation should extend beyond platform capability and technical performance to include the structured assessment of situational awareness impacts, degraded-mode readiness, and trust calibration behaviours. Incorporating human-centred evaluation criteria into procurement and modernization initiatives would help ensure that cognitive resilience is preserved alongside technological advancement.

Second, layered transparency and verification mechanisms should be treated as operational requirements rather than optional interface features. AI-enabled decision-support systems deployed in maritime contexts should support operator sensemaking through context-sensitive explanation, uncertainty signalling, and access to underlying sensor data. Formalizing such design principles within capability development frameworks would reduce the risk of automation bias and delayed anomaly detection under contested conditions.

Third, maritime CONOPSs and training doctrine should explicitly incorporate degraded-mode proficiency and AI-off scenario exposure. The regular rehearsal of manual navigation, anomaly response, and rapid transition away from automated modes would mitigate the skill erosion associated with extended supervisory roles. Scenario-based exercises emphasizing rare but high-consequence events are particularly relevant for Arctic and distributed operations, where environmental and electromagnetic disruptions may compound system vulnerabilities.

Fourth, the CAF should develop defence-relevant cognitive evaluation frameworks tailored to AI-enabled maritime operations. Current research lacks standardized metrics for defence contexts; however, structured simulation, behavioural reliance indicators, and intervention timing analysis can be integrated into experimentation and capability validation activities. Establishing consistent evaluation protocols would support responsible AI integration and enhance interoperability with allied forces pursuing similar modernization objectives.

Taken together, these measures position cognitive resilience as a strategic enabler of Canada's defence posture. As AI-enabled maritime systems become increasingly integrated into surveillance, navigation, and command support functions, preserving calibrated trust, verification capacity, and degraded-mode readiness will be essential to sustaining operational effectiveness and legitimacy in contested maritime environments.

Conclusion

Human factors risks associated with overreliance on AI-enabled systems in maritime operations were examined through a focused analysis of situational awareness and vigilance, skill retention, and trust calibration. Drawing on empirical, qualitative, and review evidence from the maritime autonomy literature, the findings indicate that these elements function as an interconnected system rather than as isolated variables. AI-driven role reconfiguration toward supervisory monitoring reduces sustained engagement with the operational environment, constrains opportunities for cognitive rehearsal, and shapes reliance behaviour in ways that can reinforce automation dependence over time.

Across ferry field studies, simulator research, ethnographic analyses, and systematic reviews, consistent patterns emerge: prolonged monitoring roles are associated with reduced vigilance, diminished readiness for degraded-mode intervention, and unstable trust dynamics. These effects are not framed here as deterministic or uniformly quantified. Rather, they represent plausible and convergent cognitive mechanisms that warrant deliberate attention during AI adoption in maritime settings.

For maritime defence and security organizations operating in distributed, time-pressured, and potentially contested environments, the implications extend beyond efficiency. AI-enabled systems increasingly mediate how information is perceived, fused, and acted upon. When positioning inputs or sensor data are corrupted yet internally coherent within fused displays, the human operator may become the final mechanism for anomaly detection. Under such conditions, mission assurance depends not only on technological performance but on the preservation of calibrated trust, vigilance, and degraded-mode readiness.

The contribution of this analysis lies not in offering technical prescriptions for specific systems but in clarifying where overreliance risks are most likely to emerge and how they interact through the Situational awareness–Skill–Trust loop. By synthesizing converging evidence into a mechanism-driven framework, this work supports the more deliberate integration of human-centred design, training, and evaluation into AI-enabled maritime systems. Ensuring that human–AI interaction remains resilient under degraded or adversarial conditions should be treated as a core component of operational capability rather than as a secondary consideration.

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