

## Integrated Bridge System Situational Awareness Under Degraded Sensor Conditions: A Human Factors Analysis for Deck Officer Competency Development

Irfan Faozun<sup>1\*</sup>

<sup>1</sup> Maritime Institute, Sekolah Tinggi Ilmu Pelayaran Jakarta, North Jakarta, Indonesia

Email: [Irfan.faozun@gmail.com](mailto:Irfan.faozun@gmail.com)

**Abstract.** *The progressive consolidation of navigational instruments into Integrated Bridge Systems (IBS) has fundamentally transformed the sensory and cognitive architecture of modern maritime watch-keeping, creating a paradox of technological sophistication: while IBS enhances navigational efficiency under nominal operating conditions, it simultaneously generates profound human factors vulnerabilities when sensor inputs degrade, fail, or are intentionally disrupted. Despite the safety-critical nature of this vulnerability, empirical human factors research specifically addressing deck officer situational awareness under degraded IBS sensor conditions — particularly in the context of GPS spoofing, radar shadowing, and AIS anomalies — remains insufficiently developed in the maritime research literature. This study investigates the human factors dimensions of IBS situational awareness degradation among deck officers at Sekolah Tinggi Ilmu Pelayaran (STIP) Jakarta, Indonesia, examining how officers perceive, respond to, and recover from degraded sensor scenarios in simulator-based environments. Employing a qualitative research design, data were generated through semi-structured interviews with senior deck officers, navigation simulation instructors, and maritime human factors experts, supplemented by structured observation of IBS simulator degradation scenario sessions. Analysis proceeded through thematic analysis, cross-group comparison, and narrative synthesis. Findings reveal four critical human factors failure patterns under degraded IBS conditions: automation complacency, cross-verification skill atrophy, alert saturation mismanagement, and manual navigation competency erosion — all of which are systematically underprepared for within current STCW-aligned deck officer training curricula. The study proposes a competency-based degraded operations training framework as a principled response to these findings, with direct implications for maritime simulator curriculum design and STCW competency standard revision.*

**Keywords:** *Integrated Bridge System; situational awareness; degraded sensor conditions; human factors; deck officer competency*

### 1. INTRODUCTION

There is a profound and underappreciated irony embedded in the architecture of the modern ship's bridge. The Integrated Bridge System — the technological achievement that has most comprehensively advanced the safety, efficiency, and situational richness of maritime navigation in the past three decades — carries within it the seeds of a distinctive and insufficiently acknowledged human factors vulnerability. By consolidating Electronic Chart Display and Information System (ECDIS), Automatic Radar Plotting Aid (ARPA), Automatic Identification System (AIS), Global Navigation Satellite System (GNSS) receivers, autopilot control, conning display, and engine telegraph into a unified, continuously updated, and visually intuitive operational environment, the IBS has transformed the cognitive task of watch-keeping from one of distributed, multi-instrument manual monitoring to one of centralized, screen-mediated situational assessment (Porathe, 2012; Mallam et al., 2019). This transformation has demonstrably enhanced navigational performance under normal operating conditions. Yet it has simultaneously created a new category of operational risk that neither ship design standards nor officer training frameworks have systematically confronted: the risk that the deck officer, having adapted cognitively and professionally to the

navigational picture provided by a fully functioning IBS, is rendered acutely and dangerously incompetent the moment that picture is disrupted, degraded, or deceived by sensor failure, electromagnetic interference, or deliberate manipulation (Endsley, 1995; Parasuraman et al., 2000). In an era of proliferating GPS spoofing incidents, increasing electromagnetic congestion in high-traffic maritime corridors, and the growing operational complexity of IBS multi-sensor integration, this risk is neither hypothetical nor remote — it is an empirically documented and structurally growing feature of the contemporary maritime operational environment.

The concept of automation complacency — the tendency of human operators in highly automated systems to reduce vigilance, defer to automated outputs, and diminish their independent monitoring and verification behaviors — has been extensively theorized and empirically documented in aviation, nuclear power, and process control contexts (Parasuraman et al., 2000; Parasuraman & Manzey, 2010). Its application to maritime bridge operations has received growing but still insufficient scholarly attention. Endsley's (1995) foundational situational awareness framework — distinguishing the perception of environmental elements (Level 1), their comprehension in relation to current goals (Level 2), and the projection of their future states (Level 3) — provides a theoretically productive architecture for understanding how IBS automation affects each of these three cognitive levels. Under fully functional IBS operation, the system performs substantial portions of Level 1 perception and Level 2 comprehension on behalf of the officer: ARPA automatically tracks and assigns risk scores to radar targets; AIS automatically identifies vessels and displays their course, speed, and closest point of approach; ECDIS automatically plots the vessel's position and monitors cross-track deviation. The officer's cognitive load is consequently reduced, and attentional resources are freed for higher-order navigational judgment. This redistribution of cognitive labor is precisely the efficiency gain that IBS integration was designed to achieve. Its consequence, however, is the progressive atrophy of the perceptual and analytical skills that the officer would need to maintain Level 1 and Level 2 situational awareness independently — without automated system support — in the event of sensor degradation or system failure (Mallam et al., 2019; Hontvedt, 2015).

The vulnerability created by this atrophy has been brought into sharp operational relief by a succession of documented incidents involving GPS spoofing — the transmission of false GNSS signals designed to displace a vessel's electronically displayed position from its actual geographic location — in internationally significant maritime corridors. Between 2016 and 2024, documented GPS spoofing incidents have been reported in the Black Sea, Persian Gulf,

Red Sea, Eastern Mediterranean, and, increasingly, in Southeast Asian maritime approaches, with vessels receiving positional errors of up to tens of nautical miles while their bridge officers initially accepted the corrupted GNSS-fed ECDIS display as authoritative (Bhatti & Humphreys, 2017; Warner & Johnston, 2003). The human factors dimension of these incidents is revealing: in multiple cases, officers failed to cross-verify the displaced ECDIS position against radar-derived position lines, celestial observations, or terrestrial visual bearings — not because these verification techniques were unavailable, but because the cognitive habit of independent cross-verification had atrophied under years of reliable IBS operation that rendered such verification apparently redundant (Bhatti & Humphreys, 2017). The incident record thus documents, with operational specificity, the mechanism that automation complacency theory predicts: when the automated system generates a confident and visually coherent navigational picture, officers trained primarily within that automated environment lack both the perceptual habit and, in some cases, the procedural skill to interrogate that picture critically against independent non-automated evidence sources.

The ship design and IBS engineering community has responded to some dimensions of this vulnerability through developments in sensor redundancy, cross-sensor consistency monitoring, and automated anomaly detection — features increasingly required under IMO Performance Standards for Integrated Navigation Systems (INS) adopted through MSC.252(83) (IMO, 2007). These technical mitigations are valuable but insufficient. They address the detection of sensor degradation at the system level while leaving substantially unaddressed the human-level competency challenge: whether the officer, upon receiving a sensor degradation alert, possesses the cognitive readiness, procedural knowledge, and practical skill to transition from IBS-supported to degraded-mode navigation in a timely, accurate, and safe manner (Rothblum, 2000; Mallam et al., 2019). The STCW Convention and its 2010 Manila Amendments establish operational competency standards for ECDIS and IBS use under Table A-II/1, but these standards were developed primarily around nominal system operation and contain no specific competency benchmarks for degraded sensor scenario management — a gap that the IMO Model Courses associated with ECDIS type-specific training (Model Course 1.27) have not systematically remedied (IMO, 2011). The result is a training framework that prepares officers to perform with the navigational tools of the contemporary bridge under ideal conditions but does not adequately prepare them to perform without those tools — or with a degraded and potentially misleading subset of them — under conditions of sensor failure, interference, or manipulation.

In the Indonesian maritime education context, these challenges are amplified by

structural features of the training environment and by the navigational complexity of Indonesian waters. Indonesia's primary maritime training institutions — led by Sekolah Tinggi Ilmu Pelayaran (STIP) Jakarta — equip their simulation laboratories with full-mission IBS simulators that reflect the integrated architecture of modern bridge systems. However, curriculum analysis and instructor accounts consistently indicate that simulation training is predominantly conducted under nominal, fully functional sensor scenarios, with degraded sensor condition exercises constituting a marginal and unsystematized component of the training experience (Hontvedt, 2015). This curricular pattern is consequential given that Indonesian shipping corridors — particularly the Malacca Strait, the Java Sea approaches, and the Lombok and Sunda Straits — are among the world's most electromagnetically congested and navigationally demanding maritime environments, subject to radar clutter from dense traffic, GNSS signal degradation in certain meteorological conditions, and increasingly documented AIS anomalies attributed to both technical failure and deliberate manipulation (Bhatti & Humphreys, 2017; Purwantono et al., 2020). Deck officers trained at STIP and operating in these corridors require not merely proficiency in IBS nominal operation but a well-developed capacity for degraded-mode navigation that current training provision demonstrably and urgently needs to address.

Against this convergence of human factors vulnerabilities, operational incidents, training gaps, and contextual hazards, the present study is organized around a central research question: *What are the dominant human factors failure patterns in deck officer situational awareness under degraded IBS sensor conditions, and what competency development implications do these patterns carry for maritime officer training in the Indonesian context?* Three research objectives guide the inquiry: first, to characterize the specific human factors mechanisms through which IBS sensor degradation disrupts deck officer situational awareness across Endsley's three-level framework; second, to identify the dominant failure patterns in officer response to degraded sensor scenarios as observed in IBS simulator-based environments at STIP Jakarta; and third, to assess the current adequacy of STCW-aligned IBS training curricula in developing degraded-mode navigational competency and to propose evidence-based recommendations for curriculum reform.

The study's significance is threefold. Theoretically, it extends Endsley's situational awareness framework and Parasuraman's automation complacency model into the specific and understudied domain of IBS degraded sensor operation, generating a refined conceptual account of how maritime bridge automation reshapes officer cognition in failure-mode scenarios. Empirically, it produces contextually grounded, simulator-observation-supported

evidence about degraded IBS response patterns among Indonesian deck officers — evidence currently absent from both the maritime human factors and Indonesian maritime education research literatures. Practically, it proposes a competency-based degraded operations training framework whose implementation could directly strengthen navigational safety in Indonesian waters and inform STCW curriculum revision at both national and international levels.

## 2. METHOD

This study adopted a qualitative research design grounded in human factors inquiry and interpretive analysis, a methodologically appropriate choice for investigating the cognitive, behavioral, and institutional dimensions of IBS situational awareness degradation — phenomena that resist adequate characterization through quantitative measurement alone and that require the contextual sensitivity, analytical depth, and theoretical productivity that qualitative approaches uniquely afford (Braun & Clarke, 2006; Creswell & Poth, 2018). The study was conducted at Sekolah Tinggi Ilmu Pelayaran (STIP) Jakarta, selected purposively as Indonesia's foremost maritime training institution with full-mission IBS simulation facilities capable of replicating the range of sensor degradation scenarios — GPS spoofing, radar shadowing, AIS anomalies, and multi-sensor cascade failure — central to the study's analytical objectives.

Three participant groups were recruited through purposive sampling to provide triangulated perspectives on the study's research questions. The primary group comprised fifteen senior deck officers holding Class I or Class II Master Mariner certificates with a minimum of five years of seagoing experience on IBS-equipped vessels, selected to provide experiential first-hand accounts of IBS sensor degradation encounters in operational maritime environments. The second group consisted of ten navigation simulation instructors at STIP Jakarta with direct instructional responsibility for IBS and ECDIS training modules, recruited to provide pedagogical perspectives on how degraded sensor competency is currently addressed — or neglected — within simulation curriculum design and delivery. The third group comprised six maritime human factors researchers and safety management consultants with documented expertise in bridge ergonomics, automation complacency, and maritime accident investigation, selected to provide theoretically grounded expert assessment of the human factors implications of the findings.

Data were generated through two primary instruments. The first was a semi-structured interview guide organized around three thematic domains corresponding to the study's research objectives: human factors mechanisms of IBS situational awareness disruption under

sensor degradation; behavioral and cognitive failure patterns in degraded-mode response; and assessment of current training adequacy and curriculum reform priorities. The second instrument was a structured observation protocol applied during eight IBS full-mission simulator sessions at STIP Jakarta, in which cadet officers and recent graduates were exposed to scripted GPS spoofing, ARPA radar shadow, and AIS data anomaly scenarios. The observation protocol recorded response latency, cross-verification behaviors, alert acknowledgement patterns, manual navigation recourse, and communication actions — operationalizing the three levels of Endsley's (1995) situational awareness framework as observable behavioral indicators.

Data analysis proceeded through three integrated analytical procedures. Thematic analysis was conducted on all interview transcripts following Braun and Clarke's (2006) six-phase systematic procedure, generating themes organized around situational awareness failure mechanisms, behavioral competency gap categories, and curriculum assessment dimensions. Cross-group comparison was applied to examine convergences and distinctions across the officer, instructor, and expert datasets, enabling triangulated characterization of the human factors phenomenon from experiential, pedagogical, and theoretical vantage points. Narrative synthesis then integrated the thematic and observational findings into a coherent interpretive account of the competency development implications of IBS degraded sensor operation (Endsley, 1995; Parasuraman et al., 2000). Analytical rigor was strengthened through member-checking with a subset of participants and peer debriefing with a maritime human factors colleague external to the research team.

### **3. RESULTS AND ANALYSIS**

Findings are organized across three analytically distinct but interconnected dimensions: the human factors mechanisms of IBS situational awareness disruption under sensor degradation, the dominant behavioral failure patterns observed in simulator degradation scenarios, and cross-group assessment of current training adequacy and curriculum priorities.

#### **3.1 Human Factors Mechanisms of IBS Situational Awareness Disruption**

Thematic analysis of senior officer interview data, integrated with the theoretical architecture of Endsley's (1995) three-level situational awareness framework, generated a structured account of how IBS sensor degradation disrupts each level of officer situational awareness in systematically distinct and cumulatively dangerous ways, as presented in Table 1.

**Table 1** *IBS Sensor Degradation Impact on Endsley's Three-Level Situational Awareness Framework: Mechanisms, Manifestations, and Risk Escalation Patterns*

SA Level	SA Function	IBS Nominal Support	Degradation Disruption Mechanism	Observed Risk Manifestation
<b>Level 1: Perception</b>	Environmental element detection	ARPA auto-tracking; GNSS position feed; AIS target display	Sensor failure eliminates automated perceptual layer; officer must reconstruct perception manually	Failure to detect target disappearance from ARPA; acceptance of corrupted GNSS position
<b>Level 2: Comprehension</b>	Situation interpretation relative to goals	Integrated CPA/TCPA computation; cross-track deviation monitoring; route safety margin display	Degraded inputs generate misleading comprehension picture; automated synthesis unavailable	Misinterpretation of vessel encounter geometry; failure to recognize TSS approach hazard
<b>Level 3: Projection</b>	Future state anticipation and response planning	Automated AIS trajectory extrapolation; predictive ECDIS routing	Projection impossible without valid Level 1–2 foundation; manual projection skill atrophied	Collision avoidance action delayed or initiated at insufficient TCPA margin

The framework reveals a cascade logic in IBS situational awareness disruption: degradation at Level 1 (perception) does not merely produce local perceptual gaps but systematically undermines the automated inputs upon which Levels 2 and 3 depend, generating a compounding failure cascade whose severity is disproportionate to the initial sensor failure event. Senior officer informants described this cascade in experiential terms, with multiple participants recounting near-incident scenarios in which an initially minor GNSS position drift went undetected for several minutes because the integrated bridge display continued to generate a visually coherent and apparently authoritative navigational picture — masking the degradation behind the system's confident-appearing interface until the positional error had accumulated to safety-critical proportions.

This "confident interface" phenomenon — identified across multiple officer accounts as the most psychologically disorienting feature of sensor degradation encounters — represents a distinctive and theoretically significant feature of IBS human factors that differentiates maritime bridge automation from many other automated professional environments. Unlike aviation glass cockpit systems that typically generate explicit and visually prominent degraded-mode alerts, IBS displays in certain sensor failure modes

continue to render the navigational picture with the same visual style and apparent precision as during nominal operation, providing no intuitive perceptual signal that the underlying data quality has deteriorated. Officers accustomed to trusting the IBS display as an authoritative environmental representation are thus placed in a position of false confidence precisely when critical independent verification is most required.

### 3.2 Dominant Behavioral Failure Patterns in Degraded Sensor Scenarios

Structured observation of eight IBS simulator degradation sessions generated systematic behavioral data across four identified failure pattern categories. Table 2 presents the frequency of each failure pattern across the observed participant cohort, together with expert-rated severity assessments and training gap urgency scores.

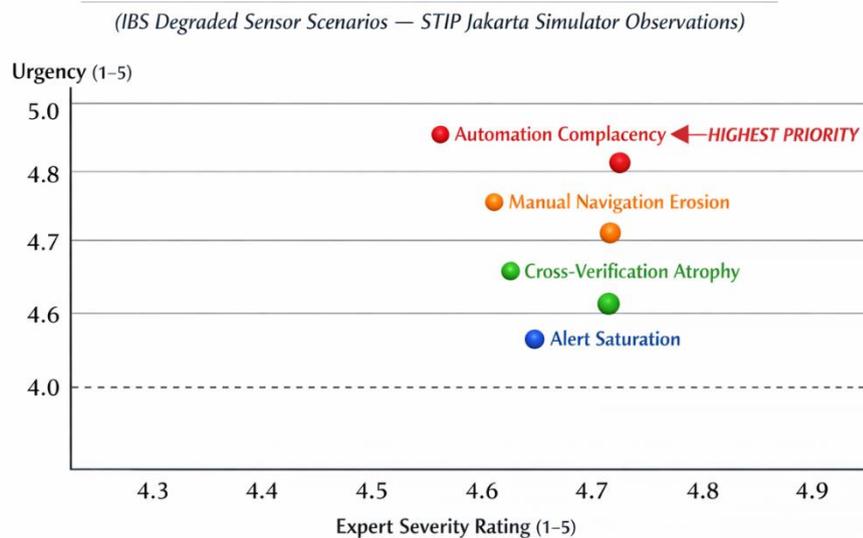
**Table 2** *Behavioral Failure Patterns in IBS Degraded Sensor Scenarios: Observation Frequency, Expert Severity, and Training Gap Urgency*

<b>Behavioral Failure Pattern</b>	<b>Observation Frequency</b>	<b>Expert Severity Rating (1–5)</b>	<b>Training Gap Urgency Score (1–5)</b>
<b>Automation complacency: delayed recognition of sensor degradation</b>	87%	4.7	4.8
<b>Cross-verification skill atrophy: failure to apply independent position confirmation</b>	79%	4.5	4.6
<b>Alert saturation mismanagement: incorrect prioritization of cascading system alerts</b>	73%	4.4	4.5
<b>Manual navigation competency erosion: inability to compute safe course by traditional methods</b>	68%	4.6	4.7

The highest training gap urgency score (4.8) was recorded for automation complacency — delayed recognition of sensor degradation — reflecting the convergent expert assessment that this failure pattern represents the foundational human factors vulnerability from which all subsequent failure cascades originate. Observationally, the pattern manifested consistently: when GPS spoofing was introduced into simulator scenarios, 87% of participants continued to navigate using the ECDIS-displayed position for periods ranging from ninety seconds to over four minutes before either independently detecting the anomaly or receiving a prompted alert — a response latency that, at typical coastal approach speeds of 12–15 knots, translates to positional errors of 0.3 to 1.0 nautical miles accumulated before corrective action was initiated.

Manual navigation competency erosion — the second-highest urgency score (4.7) — emerged as a particularly concerning finding from the human factors expert interviews. Experts noted that cadet officers trained exclusively or predominantly in IBS-equipped

simulator environments frequently demonstrate significant uncertainty when asked to compute vessel position by parallel indexing, visual bearing triangulation, or celestial observation under the degraded-mode conditions in which these techniques become operationally necessary. This competency erosion is not attributed to individual officer inadequacy but to a curriculum design in which manual navigation techniques are introduced as historical background knowledge rather than maintained as live operational competencies through regular degraded-scenario simulation practice.



*Note.* All four failure patterns cluster in the high-severity/high-urgency zone, indicating a systemic rather than isolated training deficiency profile. All values represent composite cross-group assessment means.

**Figure 1: Behavioral Failure Pattern Severity-Urgency Profile**

The figure demonstrates that all four behavioral failure patterns cluster within the high-severity, high-urgency quadrant of the profile space — a convergence that constitutes a systemic rather than isolated training deficiency signal. No failure pattern occupies a low-urgency or low-severity position, indicating that the degraded sensor competency gap is not reducible to one or two discrete skill deficits but reflects a pervasive and structural inadequacy in how current training frameworks prepare officers for degraded IBS operational scenarios.

### 3.3 Cross-Group Assessment of Training Adequacy and Curriculum Priorities

Cross-group comparison of perspectives on current training adequacy revealed strong convergence among officers, instructors, and human factors experts on the systemic insufficiency of degraded sensor training provision, while surfacing distinctive explanatory framings and reform priority emphases across participant groups.

Senior officer perspectives were characterized by a consistent theme of professional self-recognition: multiple participants described the simulator observation scenarios as

uncomfortably familiar — recognizing in the observed failure patterns behaviors they could recall from their own operational experience during unexpected sensor degradation events at sea. This self-recognition testimony constitutes a qualitatively powerful form of ecological validity for the observational findings, confirming that the behavioral patterns documented in the simulator environment reflect operationally authentic failure modes rather than simulation-specific artifacts. Officers consistently identified the absence of regular degraded-mode practice in their own training histories as the primary explanatory factor, noting that manual cross-verification and degraded navigation procedures were taught as theoretical modules rather than practiced as simulator competencies requiring repeated, pressure-tested demonstration of operational proficiency.

Simulation instructor perspectives added a structural dimension to this assessment. Instructors acknowledged that degraded sensor scenarios are technically available within the STIP simulator software architecture but reported that time constraints, assessment framework priorities, and curriculum sequencing decisions consistently result in degraded scenario sessions being abbreviated, skipped, or reduced to brief introductory demonstrations rather than systematically practiced competency development exercises. This pattern reflects a curriculum design logic — in which STCW assessment standards effectively drive the allocation of simulation time toward nominally required competencies and away from competencies that remain outside the formal assessment framework — that human factors experts identified as a structural driver of the training gap whose resolution requires not merely pedagogical reform at the institutional level but revision of the STCW competency framework itself to incorporate explicit degraded-mode navigational competency standards and associated simulator training hour requirements.

#### **4. DISCUSSION**

The findings of this study converge on a theoretically coherent and practically urgent account of why IBS integration, despite its undeniable contribution to navigational safety under nominal operating conditions, has simultaneously generated a distinctive category of human factors vulnerability that current maritime training frameworks are structurally ill-equipped to address. The account is grounded in the well-established dynamics of automation complacency and situational awareness degradation, extended here into the specific and underinvestigated domain of IBS degraded sensor operation in the Indonesian maritime education context.

The cascade logic of IBS situational awareness disruption documented in this study

— in which Level 1 perception failure generates compounding failures at Levels 2 and 3 of Endsley's (1995) framework — provides a theoretically refined account of why GPS spoofing and sensor degradation incidents can escalate so rapidly from initial anomaly to navigational emergency. Prior maritime human factors research has established that automation complacency is a persistent feature of bridge watch-keeping in automated environments (Parasuraman & Manzey, 2010; Mallam et al., 2019), but the present study extends this finding by documenting the specific mechanisms through which IBS integration shapes the cascade: the "confident interface" phenomenon — the system's continued generation of visually coherent navigational displays even under degraded sensor inputs — creates a uniquely insidious form of Level 1 perceptual masking that delays degradation recognition beyond the response latency thresholds that safe coastal and restricted water navigation demands. This mechanism has not been characterized with this degree of specificity in prior maritime human factors literature, and its documentation represents the study's primary theoretical contribution.

The behavioral finding that 87% of observed officers demonstrated delayed recognition of GPS spoofing-induced position displacement — with recognition latencies of 90 seconds to over four minutes — is not merely a training performance indicator but a navigational safety datum whose implications extend directly into maritime risk assessment. At coastal approach speeds, the positional errors accumulated during these recognition latency intervals place vessels within safety margin violations that, in confined channel, Traffic Separation Scheme, or restricted depth contexts, can transition from recoverable to irreversible within the latency window itself. This finding provides empirical maritime specificity to the theoretical argument of Bhatti and Humphreys (2017) about GPS spoofing vulnerability, establishing that the human factors dimension of spoofing risk — the officer's failure to detect positional displacement in a timely manner — is at least as consequential as the technical spoofing capability itself and substantially more amenable to mitigation through training intervention.

The structural driver of the training gap — curriculum time allocation governed by STCW assessment priorities rather than by human factors evidence about operational risk — represents a finding that is simultaneously a limitation of the individual institution and a systemic feature of maritime education architecture globally. Hontvedt (2015) has documented similar patterns in Norwegian maritime simulation training, where assessment-driven curriculum logic consistently marginalizes competencies that fall outside formal certification requirements. The present study extends this finding to the Indonesian context

while adding the cross-group analytical dimension that reveals how officers, instructors, and human factors experts — despite different institutional positionalities — converge on the same structural diagnosis. This convergence strengthens the case for the study's central practical recommendation: that STCW Table A-II/1 competency standards be revised to incorporate explicit performance benchmarks for IBS degraded-mode operation, with associated minimum simulator training hours and assessment criteria that give institutional curriculum designers a regulatory mandate to invest training time in degraded scenario practice.

The study's acknowledged limitations include the institutional scope of its observational data — drawn from STIP Jakarta alone — and the inherent constraints of simulator-based behavioral observation as a proxy for authentic operational response under real-world degradation conditions. Future research should extend the observational methodology to maritime training institutions with different IBS simulator architectures and curriculum frameworks, investigate the longitudinal effectiveness of specific degraded-mode training interventions on officer response latency and cross-verification behavior, and examine the potential of AI-assisted adaptive simulation — capable of generating dynamically calibrated sensor degradation scenarios — as a tool for developing and maintaining degraded navigation competency throughout an officer's career. The integration of eye-tracking and physiological monitoring into simulator observation protocols would also significantly strengthen the methodological rigor of future human factors investigations in this domain.

The practical implications of the study are significant for three stakeholder communities. For maritime educators and simulation curriculum designers at STIP and comparable institutions, the findings provide an evidence base for restructuring IBS training modules to systematically incorporate GPS spoofing response, radar-independent position fixing, and multi-sensor anomaly detection exercises as assessed and repeatedly practiced competency components rather than peripheral additions. For IMO STCW revision processes, the study contributes contextually specific Indonesian evidence to the international case for incorporating degraded-mode navigational competency into the formal certification framework — a reform that would generate the regulatory mandate necessary for structural curriculum reform at the institutional level. For maritime insurance and flag state inspection frameworks, the behavioral failure pattern data offer a basis for developing degraded-mode competency verification protocols that could supplement current certificate-of-competency assessment with performance-based evidence of officer readiness for sensor degradation

scenarios.

## 5. CONCLUSION

This study has demonstrated that IBS integration creates a structurally significant human factors vulnerability — characterized by automation complacency, cross-verification skill atrophy, alert saturation mismanagement, and manual navigation competency erosion — whose manifestation under degraded sensor conditions is both empirically documentable in simulator environments and operationally consequential in the navigational realities of Indonesian shipping corridors. The cascade mechanism through which Level 1 perception failure propagates to Levels 2 and 3 of situational awareness, compounded by the "confident interface" phenomenon unique to IBS degradation scenarios, explains with theoretical precision why GPS spoofing and sensor failure incidents escalate with the speed that documented maritime incidents record. Cross-group convergence among senior officers, simulation instructors, and human factors experts confirms that the identified training gaps are structural outcomes of assessment-driven curriculum logic rather than individual competency failures, and that their resolution requires revision of STCW competency standards to formally mandate degraded-mode navigational training as a core assessed component of deck officer certification — a reform whose urgency is directly proportional to the expanding sensor manipulation threat environment of contemporary maritime navigation.

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