International Journal of Scientific Multidisciplinary Research (IJSMR)
Vol. 4, No. 9, 2026: 2127 - 2142

Reliance Ahead of Understanding: Practitioner Assessment of AIS Effectiveness in Vessel Traffic Service Operations at Merak, Sunda Strait

Rob Danang Priatmaja[1]*, Syairi Anwar[2], Nursyamsu[3], Yollanda Octavitri[4]
Banten Maritime Polytechnic, Tangerang, Indonesia
Corresponding Author: Rob Danang Priatmaja
robdanang.poltekpel@gmail.com

ARTICLEINFO

Keywords: Automatic Identification System, Vessel Traffic Service, Collision prevention, Sunda Strait, Maritime situational awareness

Received : 14, July
Revised : 13, August
Accepted: 10, September

ABSTRACT

This study examines practitioner assessment of AIS in supporting Vessel Traffic Service operations and collision prevention at Merak, on the Sunda Strait. A descriptive quantitative survey using a five-point Likert instrument was administered to 60 respondents comprising VTS Merak operators, ship crew, and navigation officers, supplemented by limited observation and interview. Four aspects were assessed. Effectiveness for safety attained the highest mean at 4.32, followed by the perceived need for further development at 4.28, implementation within VTS operations at 4.18, and understanding of AIS functions at 4.06. The profile discloses a pattern the study terms reliance ahead of understanding: the aspect concerning operational benefit scored highest while the aspect concerning knowledge of the system scored lowest, a gap of 0.26 scale points. Respondents simultaneously endorsed AIS and identified persistent constraints, principally signal interference and demand for technical training, alongside support for Satellite AIS integration.

INTRODUCTION

The Automatic Identification System has become the principal source of vessel movement information available to shore-based traffic managers and to mariners alike. Originally mandated as a collision avoidance aid, AIS now underpins an extensive range of applications extending well beyond its original purpose, and the availability of its data has transformed maritime research as substantially as it has transformed operations (Yang et al., 2019; Svanberg et al., 2019). Within Vessel Traffic Service centres, AIS supplies the identity, position, course, and speed information upon which monitoring, advisory, and traffic organisation services depend.

The Sunda Strait presents a setting in which these capabilities are placed under particular strain. The strait connects the Indian Ocean with the Java Sea and carries dense traffic, while simultaneously accommodating the intensive ferry service linking Merak in Banten with Bakauheni in Lampung. Recognition of the resulting risk led the International Maritime Organization to approve a Traffic Separation Scheme for the strait with effect from July 2020, following earlier proposals for such a measure as a means of accident prevention (Sunaryo et al., 2015). Subsequent evaluation has examined the implementation of that scheme (Priadi et al., 2024) and the development of inshore traffic zones within it (Sobaruddin et al., 2026), while Baldauf et al. (2020) assessed the potential contribution of Vessel Traffic Services to safety in the strait specifically.

The technical literature on AIS is extensive and has advanced rapidly. Substantial bodies of work address trajectory mining and route extraction (Yan et al., 2020), anomaly detection through statistical and neural approaches (Rong et al., 2020; Wolsing et al., 2022; Nguyen et al., 2022; Zhao & Shi, 2019), and the derivation of collision risk indicators from AIS tracks (Zhang et al., 2016; Zhen et al., 2017). Tu et al. (2018) surveyed the field comprehensively from data to methodology. This work has established what AIS data can support analytically.

A substantial and rapidly advancing technical literature demonstrates what AIS data can support analytically, from trajectory extraction and anomaly detection to the derivation of collision-risk indicators (reviewed in detail in the next section). This body of work establishes the analytical potential of the data; it does not establish how the practitioners who operate the system in real time assess its usefulness, trust its output, or incorporate it into procedure — the question this study takes up.

Considerably less is known about how those who operate the system assess it. The question matters because the effectiveness of a monitoring technology in practice depends not only upon its technical capability but upon whether operators understand it, trust it, and incorporate it into procedure. Harati-Mokhtari et al. (2007) demonstrated early that AIS data reliability is compromised by human error in data entry, establishing that the system's outputs are only as sound as the practices surrounding it. More recent work on Vessel Traffic Service operations has examined resilience in everyday practice (Praetorius et al., 2015), the human factors bearing upon safe operator performance (Crestelo Moreno et al., 2022), and the cognitive and social factors involved (Sharma et al., 2025).

Within the Indonesian context, practitioner assessment of AIS has attracted little systematic study, notwithstanding that the country's archipelagic geography renders vessel traffic management unusually consequential. This study accordingly examines how VTS operators, ship crew, and navigation officers at Merak assess the effectiveness of AIS in supporting traffic management and collision prevention. Two objectives are pursued: to establish the level at which practitioners assess AIS across the dimensions of understanding, implementation, effectiveness, and developmental need; and to identify the constraints they report. The contribution lies less in the absolute level of the scores obtained, which proved uniformly favourable, than in their ordering, which discloses a pattern with direct implications for training policy.

THEORETICAL REVIEW

AIS as a Data Source and Its Limitations

AIS transmits vessel identity, position, course, speed, and voyage particulars at intervals determined by vessel dynamics, and its reception by shore stations and by other vessels supplies a near-continuous picture of traffic. The analytical possibilities this creates have been extensively exploited. Tu et al. (2018) surveyed applications spanning trajectory reconstruction, behaviour classification, and route prediction, and Yang et al. (2019) assessed critically how AIS data have enriched maritime research across disciplines. Yan et al. (2020) demonstrated the extraction of maritime routes from raw position reports, and Rong et al. (2020) applied data mining to route characterisation and anomaly detection.

Anomaly detection has become a substantial subfield. Wolsing et al. (2022) reviewed recent approaches, and Nguyen et al. (2022) developed a probabilistic neural representation of AIS tracks for detecting departures from normal behaviour. Zhao and Shi (2019) combined density-based clustering with recurrent neural networks to the same end. The maturity of these methods indicates that the constraint upon AIS-based surveillance is increasingly the quality of the input rather than the sophistication of the analysis.

That input is imperfect. Harati-Mokhtari et al. (2007) documented systematic deficiencies in AIS data arising from manual entry error, incorrect static data, and inconsistent updating, and concluded that reliability implications for human error must be addressed at the level of operating practice. Integrity concerns have since broadened to encompass deliberate falsification: Androjna et al. (2021) documented AIS spoofing through case study, Androjna et al. (2020) assessed the wider cyber challenges facing maritime navigation, and Goudossis and Katsikas (2018) proposed cryptographic measures toward a secure AIS. For an operator relying upon AIS for traffic management, these vulnerabilities establish that the system supplements rather than supplants visual and radar observation.

Vessel Traffic Services and the Human Operator

A Vessel Traffic Service exists to improve the safety and efficiency of navigation within a defined area, and its effectiveness rests upon the capacity of operators to construct and maintain an accurate picture of traffic. Praetorius et al. (2015) modelled VTS as a resilient system, examining how operators sustain performance under everyday variability rather than only under exceptional conditions. Crestelo Moreno et al. (2022) conducted a systematic review of the human factors bearing upon safe VTS operator performance, and Sharma et al. (2025) reviewed the cognitive and social factors involved in VTS operations more broadly.

Fatigue has emerged as a specific concern. Li et al. (2020) identified the causal factors and symptoms of task-related fatigue among VTS operators through a task-driven approach, and Crestelo Moreno et al. (2023) characterised fatigue as a key human factor within VTS as a complex sociotechnical system. Relling et al. (2021) examined the prospective contribution of VTS to safe coexistence between automated and conventional vessels, indicating that the operator's role will expand rather than diminish as autonomy increases. Baldauf et al. (2020) assessed the potential of VTS to ensure safety of maritime transportation in the Sunda Strait specifically, which situates the present study directly.

Collision Risk and Its Assessment

Collision prevention constitutes the central safety function that AIS supports. Chen et al. (2019) reviewed the state of the art in probabilistic risk analysis for ship-ship collision, and Zhang and Meng (2019) developed a probabilistic ship domain formulation with application to collision risk assessment. Zhen et al. (2017) proposed an analytic framework for real-time multi-vessel risk assessment intended for traffic surveillance, a formulation directly applicable to the VTS context. Zhang et al. (2016) demonstrated the detection of possible near-miss encounters from AIS data, permitting risk to be quantified from routine traffic rather than only from casualties.

The translation of risk assessment into avoidance action is governed by the International Regulations for Preventing Collisions at Sea. Garcia Maza and Arguelles (2022) analysed critically the incorporation of these regulations into collision avoidance algorithms, and Ahmed et al. (2021) developed a compliant fuzzy-based system for multiple-ship encounters. Studies of comparable congested waters provide points of comparison: Qu et al. (2011) assessed collision risk in the Singapore Strait, Zaman et al. (2021) analysed traffic there using AIS data, and Nofandi et al. (2022) examined traffic density in the Malacca-Singapore corridor through a vessel traffic system.

Satellite AIS and System Development

Terrestrial AIS reception is limited by line of sight, which leaves coverage gaps beyond coastal range. Satellite reception addresses this constraint, and its feasibility and performance were established by Eriksen et al. (2006) and analysed in detail by Cervera et al. (2011), who quantified the message collision problem arising when a satellite footprint encompasses many transmitting vessels. Fournier et al. (2018) reviewed the applications of satellite AIS across more than a decade of development, and Soldi et al. (2021) situated the technology within the broader architecture of space-based maritime surveillance.

For a strait such as the Sunda, satellite reception offers redundancy against terrestrial outage as much as extended coverage.

Situational Awareness and e-Navigation

AIS is one element within a wider movement toward integrated navigational information. Weintrit (2013) set out the principal potential solutions constituting the e-navigation concept, and Baldauf et al. (2014) examined its potential for enhanced collision avoidance support specifically. Sharma et al. (2019) determined the situation awareness information requirements for maritime navigation through goal-directed task analysis, establishing what information navigators actually need rather than what systems happen to supply. van de Merwe et al. (2022) reviewed systematically the relationships among agent transparency, situation awareness, mental workload, and operator performance, a set of relationships central to the design of any decision-support system.

Experience with earlier mandated systems is instructive. Car et al. (2020) examined the navigator's use of position fixing before and after the implementation of electronic chart display systems and documented the implications for navigational safety, illustrating that the introduction of a capable system does not by itself guarantee improved practice. Studies of technology acceptance in the maritime sector indicate that behavioural intention to use new systems depends upon perceived usefulness and ease of use as much as upon capability (Kim et al., 2025; Bacnar et al., 2025), and simulator-based training constitutes the principal vehicle through which competence with such systems is developed (Kim et al., 2021).

Research Gap

Three gaps emerge. First, the AIS literature is dominated by algorithmic exploitation of the data, with comparatively little attention to how the practitioners who depend upon the system assess it. Second, VTS human factors research has developed principally in European and East Asian settings, and Indonesian operations are underrepresented notwithstanding the strategic importance of the archipelagic straits. Third, studies of the Sunda Strait have concentrated upon the Traffic Separation Scheme as a routeing measure rather than upon the information systems that support its operation. The present study addresses these gaps through a practitioner survey at Merak.

METHODOLOGY

Design

The study employed a descriptive quantitative design executed through survey. No manipulation or treatment was applied to respondents; the purpose was to characterise perception and experience as they exist. A survey approach was selected because it permits data to be gathered from a dispersed population of practitioners within a limited period, and a five-point Likert format was adopted because it is readily understood by respondents and yields ordinal data amenable to descriptive summary. Survey data were supplemented by limited observation of VTS operations and by interviews with selected respondents drawn from both vessel crew and shore-based staff, in order to establish the correspondence between reported perception and observed practice.

Population and Sample

The population comprised personnel professionally engaged with AIS in the Merak area. A sample of 60 respondents was drawn from this population, comprising VTS Merak operators, ship crew members, and navigation officers. Respondents were selected on the basis of direct operational engagement with AIS, on the ground that assessment of a system's effectiveness requires working familiarity with it. The composition of the sample across the three groups permits the perspectives of shore-based traffic managers and of shipboard users to be represented within a single dataset.

Instrument

The questionnaire was organised into four aspects. The first assessed understanding and knowledge, addressing the respondent's grasp of the fundamental concept of AIS, its functions, the categories of data it transmits, and its integration with other VTS equipment and services. The second assessed implementation and operation, addressing the use of AIS in monitoring vessel traffic, in providing early warning of navigational hazard, and in facilitating coordination between VTS and vessels. The third assessed effectiveness, addressing the contribution of AIS to accident prevention, operational efficiency, and decision-making. The fourth assessed challenges and developmental need, addressing constraints encountered in use and the requirement for further system development. The instrument comprised 25 statement items distributed across six constructs: perceived AIS effectiveness (5 items), operational dependence on AIS (4 items), understanding of AIS functions and limitations (5 items), situational awareness in VTS operations (4 items), automation complacency/overreliance risk (4 items), and training and competence in AIS use (3 items). Each item was rated on the same five-point Likert scale described above (1 = strongly disagree to 5 = strongly agree). For reporting, the six constructs were aggregated into the four aspects presented in the Results: perceived AIS effectiveness constituted the effectiveness aspect; operational dependence and situational awareness together constituted the implementation aspect; understanding of AIS functions and limitations, together with automation complacency/overreliance — the latter conceptually representing the obverse of understanding — constituted the understanding aspect; and training and competence constituted the developmental-need aspect. Content validity was established through expert judgement by a panel of five reviewers comprising human-factors/maritime-safety academics, senior VTS/navigation-district practitioners, and a research-methodology specialist, who rated the relevance of each item on a 1–4 scale. Item-level and scale-level content validity indices were computed (I-CVI ≥ .78; S-CVI/Ave ≥ .90; Polit & Beck, 2006), with the content validity ratio (Lawshe, 1975) calculated as a supporting check; because the critical value for a five-member panel requires unanimous agreement (CVR = 1.00; Ayre & Scally, 2014), the I-CVI/S-CVI criteria were treated as the primary standard. Items failing these thresholds were revised or dropped on the basis of the panel's qualitative feedback. The revised instrument was then piloted with 20–30 respondents sharing the operator profile of the main sample but drawn from a different VTS station in a neighbouring area, so as to avoid overlap with the census-based main-survey sample, which the limited number of VTS Merak operators made feasible. Item validity in the pilot was assessed through the corrected item-total (Pearson) correlation, with an item retained where r exceeded the critical r-table value at the 5% significance level (df = n − 2) or reached $r \geq .30$ (Taber, 2018), and reliability was assessed using Cronbach's alpha computed per construct and overall, with $\alpha \geq .70$ taken as the criterion for acceptable reliability and values of .60–.70 regarded as tolerable for exploratory research with few items per dimension (Taber, 2018).

Analysis

Responses were summarised by arithmetic mean for each item and each aspect, in order to establish central tendency, and by frequency distribution, in order to characterise the dispersion of responses across the response categories. Internal consistency was assessed using Cronbach's alpha, with a threshold of 0.70 adopted as the criterion of acceptable reliability. Qualitative material from observation and interview was used interpretively, to contextualise the quantitative pattern rather than to generate independent findings.

Note on the Reported Reliability Coefficient

The reliability analysis returned a Cronbach's alpha of 1.00. This value requires comment. An alpha of unity implies perfect proportionality among item responses across all respondents, a condition that does not arise in genuine survey data, and a coefficient of this magnitude ordinarily indicates that the calculation has been performed upon aggregated aspect scores rather than upon individual items, or that a computational error has occurred. The coefficient is reported here as obtained, but no interpretive weight is placed upon it, and recomputation at item level is identified in the limitations as a necessary step prior to any further use of the instrument. The substantive findings reported below rest upon the descriptive statistics, which are unaffected by this issue.

RESULTS

Assessment Across the Four Aspects

Mean scores for the four assessed aspects are reported in Table 1 and displayed in Figure 1. All four exceeded 4.00 on the five-point scale, indicating favourable assessment throughout.

Table 1. Mean score by assessed aspect (n = 60).

Assessed aspect	**Mean score**	**Category**	**Principal content**
Effectiveness for safety	4.32	Very good	Accident prevention, operational efficiency, decision-making, situational awareness

Assessed aspect	Mean score	Category	Principal content
Need for further development	4.28	Very good	Infrastructure strengthening, data quality, Satellite AIS integration, routine training
Implementation in VTS operations	4.18	Very good	Traffic monitoring, early warning of hazard, VTS-to-vessel coordination
Understanding of AIS functions	4.06	Good	Basic concept, transmitted data categories, integration with VTS equipment

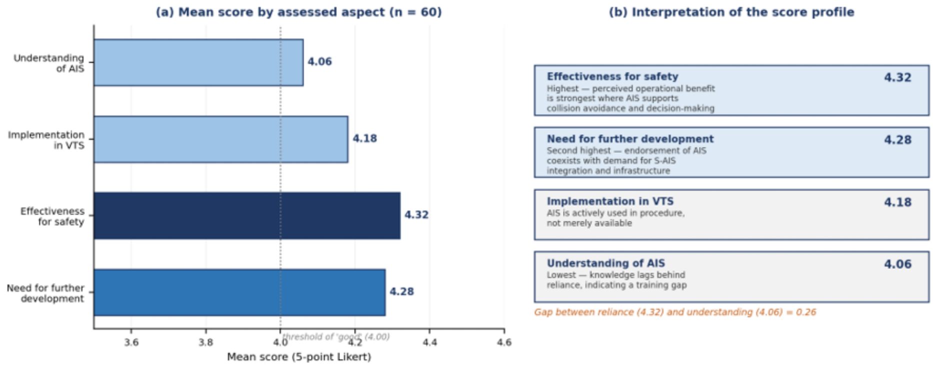

Figure 1. Mean score by assessed aspect and interpretation of the resulting profile.

Effectiveness for safety attained the highest mean at 4.32. Respondents assessed AIS as delivering substantial and tangible benefit, particularly in improving navigational safety, reducing the potential for casualty, and accelerating operational decision-making. The perceived need for further development followed at 4.28, encompassing strengthening of supporting infrastructure such as receiving and transmitting equipment and communication networks, improvement in data quality, and integration of Satellite AIS. Implementation within VTS operations recorded 4.18, indicating that AIS is not merely available but is actively and consistently employed within operating procedure, particularly in traffic monitoring, early warning, and VTS-to-vessel coordination.

Understanding of AIS functions recorded the lowest mean at 4.06. Although this remains within the favourable range, its position at the foot of the ordering is the salient feature of the result. The interval between the highest and lowest aspects is 0.26 scale points, which is modest in absolute terms but consistent in direction: the aspect concerning what AIS delivers scored higher than the aspect concerning how AIS works.

Reported Constraints

Respondents identified two categories of constraint notwithstanding their favourable overall assessment. The first concerns signal integrity, with interference and interruption of AIS reception reported as recurrent. The second concerns competence, with respondents identifying a requirement for regular technical training for both operators and vessel crew in order to maintain operational capability and to keep pace with system development. These constraints are consistent with the elevated score recorded on the developmental aspect, and indicate that endorsement of AIS coexists with a clear-eyed view of its present limitations rather than displacing it.

DISCUSSION

Reliance Ahead of Understanding

The substantive finding of this study lies in the ordering of the four aspects rather than in their level. All scored favourably, which is unsurprising among practitioners who use AIS daily and whose work would be substantially harder without it. What is informative is that effectiveness scored highest and understanding lowest. Practitioners assess the benefit AIS delivers more highly than they assess their own comprehension of how it produces that benefit. This study terms the pattern reliance ahead of understanding. This ordering is diagnostic rather than merely descriptive: it indicates that favourable overall satisfaction with AIS coexists with, and can obscure, a specific comprehension gap that pooled or single-item satisfaction measures would not reveal.

The pattern carries a specific risk. AIS is not an infallible source. Harati-Mokhtari et al. (2007) established that its data are compromised by manual entry error and inconsistent updating, and the subsequent literature on spoofing and cyber vulnerability has demonstrated that the picture AIS presents may be deliberately falsified (Androjna et al., 2021; Androjna et al., 2020; Goudossis & Katsikas, 2018). An operator who understands the mechanism by which AIS constructs its picture is equipped to recognise when that picture is implausible; an operator who relies upon it without such understanding is not. Where reliance runs ahead of understanding, the system's failure modes become invisible to those depending upon it.

This interpretation aligns with the finding of Car et al. (2020) that the introduction of electronic chart systems altered navigational practice in ways not wholly anticipated, and with the emphasis of Sharma et al. (2019) upon determining what information navigators actually require rather than what systems supply. van de Merwe et al. (2022) established that operator performance depends upon transparency of the supporting system, meaning the extent to which the operator can understand what the system is doing and why. The score profile obtained here suggests that transparency, in that sense, is the dimension on which improvement is most needed at Merak.

A Training Rather Than a Technology Deficit

The constraints respondents identified reinforce this reading. Demand for technical training was raised explicitly, and the developmental aspect scored second highest. Taken together with the comparatively low understanding score, these indicate that practitioners themselves locate the deficit in competence rather than in equipment. This is a favourable finding in one respect, since training is more readily and cheaply addressed than infrastructure, and it accords with the wider evidence that competence with mandated navigational systems must be actively developed rather than assumed to follow from their installation (Kim et al., 2021).

The VTS human factors literature indicates what such training should address. Praetorius et al. (2015) characterised VTS as a system whose safety derives from operators' capacity to adapt to everyday variability, and Crestelo Moreno et al. (2022) and Sharma et al. (2025) identified the cognitive and social factors bearing upon that capacity. Li et al. (2020) and Crestelo Moreno et al. (2023) established fatigue as a specific determinant of operator performance. Training addressed solely to system operation, without attention to these factors, is unlikely to close the gap identified here.

Signal Integrity and the Case for Satellite AIS

The reported interruption of AIS reception has both operational and analytical consequence. Operationally, an intermittent picture undermines the continuity of surveillance upon which traffic organisation depends. Analytically, gaps in AIS coverage degrade the anomaly detection and risk assessment methods that the technical literature has developed (Wolsing et al., 2022; Nguyen et al., 2022; Zhang et al., 2016), since these presuppose continuous tracks. Respondents' support for Satellite AIS integration is therefore well founded: satellite reception provides redundancy against terrestrial outage as well as extended coverage (Eriksen et al., 2006; Cervera et al., 2011; Fournier et al., 2018; Soldi et al., 2021).

The limitation of satellite reception should nevertheless be recognised. Cervera et al. (2011) quantified the message collision problem arising where a satellite footprint encompasses many simultaneously transmitting vessels, which is precisely the condition obtaining over a congested strait. Satellite AIS is accordingly a complement to terrestrial reception rather than a substitute for it, and investment in it should not displace maintenance of shore-based infrastructure.

Implications for the Sunda Strait

The findings acquire additional significance in the context of the Sunda Strait. Sunaryo et al. (2015) proposed the Traffic Separation Scheme as an accident prevention measure, and Priadi et al. (2024) subsequently evaluated its implementation, while Sobaruddin et al. (2026) examined the development of inshore traffic zones. Baldauf et al. (2020) assessed the potential contribution of VTS to safety in the strait. A routeing measure, however, delivers its benefit only if compliance can be observed and departures addressed, and observation depends upon the information system whose limitations this study documents. The reliability of AIS reception is therefore not a peripheral technical matter but a precondition for the effectiveness of the routeing measure itself.

Comparison with other congested straits reinforces the point. Qu et al. (2011) assessed collision risk in the Singapore Strait, and Zaman et al. (2021) and Nofandi et al. (2022) analysed traffic there using AIS and vessel traffic systems respectively.

The analytical capability demonstrated in those studies presupposes continuous, reliable AIS coverage. Where such coverage is intermittent, the corresponding analysis cannot be performed, and the traffic manager operates without the quantitative situational picture that comparable corridors enjoy.

Contribution to the Literature

This finding extends the VTS human-factors literature in three respects. First, where prior work has established in general terms that VTS effectiveness depends on operator competence (Praetorius et al., 2015; Crestelo Moreno et al., 2022; Sharma et al., 2025), the present result shows specifically where that competence is weakest relative to practitioners' own sense of the system's benefit, a distinction that pooled satisfaction measures common in this literature do not capture. Second, the finding responds directly to the gap identified in the Introduction: practitioner assessment of AIS, as distinct from algorithmic exploitation of AIS data, has attracted little study, and almost none in the Indonesian archipelagic setting where such systems carry particular safety weight. Third, by locating the deficit in understanding rather than in infrastructure, the study reframes the priority for the Sunda Strait specifically: within Baldauf et al.'s (2020) broader assessment of VTS potential in the strait, the present evidence points to operator training, rather than further system procurement, as the more immediately tractable lever for improvement.

Limitations

Five limitations qualify these findings. First, the study measures perception rather than performance: no attempt was made to relate assessed effectiveness to casualty rates, near-miss frequency, or any objective indicator of traffic safety. Second, the reported Cronbach's alpha of 1.00 is anomalous, as set out in the methodology, and the instrument's internal consistency should be regarded as unestablished pending recomputation at item level. Third, the sample of 60 respondents was drawn from a single location and its composition across the three occupational groups is not reported in a manner permitting between-group comparison, which would have been informative given that shore-based and shipboard users engage with AIS differently. Fourth, favourable responses may reflect acquiescence or social desirability, particularly among respondents whose employer operates the system under assessment. Fifth, the study reports aspect means without dispersion statistics, so the degree of consensus underlying each mean cannot be evaluated.

CONCLUSIONS AND RECOMMENDATIONS

This study examined practitioner assessment of AIS effectiveness in supporting Vessel Traffic Service operations and collision prevention at Merak. Sixty VTS operators, ship crew, and navigation officers assessed four aspects, all favourably: effectiveness for safety at 4.32, developmental need at 4.28, implementation at 4.18, and understanding at 4.06. The ordering of these scores constitutes the substantive finding. Practitioners assess the benefit AIS delivers more highly than they assess their comprehension of how it operates, a pattern of reliance ahead of understanding that leaves the system's failure modes less visible to those depending upon it than is desirable. Respondents identified signal interference and demand for technical training as the principal constraints, and supported Satellite AIS integration.

Three recommendations follow. First, training for VTS operators and vessel crew should address the mechanism and the limitations of AIS, including data entry dependence, coverage gaps, and susceptibility to falsification, rather than operation of the interface alone, so that reliance is matched by the capacity to recognise when the picture is unreliable. Second, the reliability of terrestrial AIS reception in the Merak approaches should be assessed instrumentally and remedied, since continuity of the traffic picture conditions both operational surveillance and the effectiveness of the Traffic Separation Scheme. Third, Satellite AIS should be pursued as a source of redundancy complementing terrestrial reception rather than as a substitute for maintaining it.

FURTHER STUDY

Four directions for further work are indicated. First, the instrument should be recomputed at item level and its internal consistency re-established, after which the aspect structure could be examined through exploratory factor analysis to confirm that the four aspects are empirically distinguishable. Second, perception should be triangulated against objective indicators, including AIS message reception statistics, documented coverage outages, and near-miss encounters derived from track data following the method of Zhang et al. (2016). Third, responses should be disaggregated by occupational group, since shore-based operators and shipboard users engage with AIS through different interfaces and for different purposes, and their assessments may diverge in ways the pooled mean conceals. Fourth, a longitudinal design spanning the implementation of any training or infrastructure intervention would establish whether the gap between reliance and understanding narrows in response.

ACKNOWLEDGMENT

The authors express their gratitude to the Director of Politeknik Pelayaran Banten and the institutional leadership, to the Head of the Centre for Research and Community Service, and to the management and operators of VTS Merak. Thanks are also due to the ship crew and navigation officers who completed the questionnaire and gave their time to interview.

REFERENCES

Ahmed, Y. A., Hannan, M. A., Oraby, M. Y., & Maimun, A. (2021). COLREGs compliant fuzzy-based collision avoidance system for multiple ship encounters. Journal of Marine Science and Engineering, 9(8), Article 790. https://doi.org/10.3390/jmse9080790

Androjna, A., Brcko, T., Pavic, I., & Greidanus, H. (2020). Assessing cyber challenges of maritime navigation. Journal of Marine Science and Engineering, 8(10), Article 776. https://doi.org/10.3390/jmse8100776

Androjna, A., Perkovic, M., Pavic, I., & Miskovic, J. (2021). AIS data vulnerability indicated by a spoofing case-study. Applied Sciences, 11(11), Article 5015. https://doi.org/10.3390/app11115015

Bacnar, D., Baric, D., & Ogrizovic, D. (2025). Charting the future of maritime education and training: A technology-acceptance-model-based pilot study on students' behavioural intention to use a fully immersive VR engine room simulator. Applied System Innovation, 8(3), Article 84. https://doi.org/10.3390/asi8030084

Baldauf, M., Benedict, K., & Kruger, C. (2014). Potentials of e-Navigation: Enhanced support for collision avoidance. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 8(4), 613-617. https://doi.org/10.12716/1001.08.04.18

Baldauf, M., Claresta, G., & Nugroho, T. F. (2020). Vessel Traffic Services (VTS) to ensure safety of maritime transportation: Studies of potentials in Sunda Strait. IOP Conference Series: Earth and Environmental Science, 557(1), Article 012068. https://doi.org/10.1088/1755-1315/557/1/012068

Car, M., Brcic, D., Zuskin, S., & Svilicic, B. (2020). The navigator's aspect of PNC before and after ECDIS implementation: Facts and potential implications towards navigation safety improvement. Journal of Marine Science and Engineering, 8(11), Article 842. https://doi.org/10.3390/jmse8110842

Cervera, M. A., Ginesi, A., & Eckstein, K. (2011). Satellite-based vessel Automatic Identification System: A feasibility and performance analysis. International Journal of Satellite Communications and Networking, 29(2), 117-142. https://doi.org/10.1002/sat.957

Chen, P., Huang, Y., Mou, J., & van Gelder, P. H. A. J. M. (2019). Probabilistic risk analysis for ship-ship collision: State-of-the-art. Safety Science, 117, 108-122. https://doi.org/10.1016/j.ssci.2019.04.014

Crestelo Moreno, F., Roca Gonzalez, J., Suardiaz Muro, J., & Garcia Maza, J. A. (2022). Relationship between human factors and a safe performance of vessel traffic service operators: A systematic qualitative-based review in maritime safety. Safety Science, 155, Article 105892. https://doi.org/10.1016/j.ssci.2022.105892

Crestelo Moreno, F., Soto-Lopez, V., Menendez-Telena, D., Roca-Gonzalez, J., Suardiaz Muro, J., Roces, C., Paino, M., Fernandez, I., & Diaz-Secades, L. A. (2023). Fatigue as a key human factor in complex sociotechnical systems: Vessel Traffic Services. Frontiers in Public Health, 11, Article 1160971. https://doi.org/10.3389/fpubh.2023.1160971

Eriksen, T., Hoye, G., Narheim, B., & Meland, B. J. (2006). Maritime traffic monitoring using a space-based AIS receiver. Acta Astronautica, 58(10), 537-549. https://doi.org/10.1016/j.actaastro.2005.12.016

Fournier, M., Casey Hilliard, R., Rezaee, S., & Pelot, R. (2018). Past, present, and future of the satellite-based automatic identification system: Areas of applications (2004-2016). WMU Journal of Maritime Affairs, 17(3), 311-345. https://doi.org/10.1007/s13437-018-0151-6

Garcia Maza, J. A., & Arguelles, R. P. (2022). COLREGs and their application in collision avoidance algorithms: A critical analysis. Ocean Engineering, 261, Article 112029. https://doi.org/10.1016/j.oceaneng.2022.112029

Goudossis, A., & Katsikas, S. K. (2018). Towards a secure automatic identification system (AIS). Journal of Marine Science and Technology, 24(2), 410-423. https://doi.org/10.1007/s00773-018-0561-3

Harati-Mokhtari, A., Wall, A., Brooks, P., & Wang, J. (2007). Automatic Identification System (AIS): Data reliability and human error implications. Journal of Navigation, 60(3), 373-389. https://doi.org/10.1017/S0373463307004298

Kim, K., Lee, C., & Lim, D. (2025). Understanding seafarers' acceptance of the transition to alternative fuels in shipping through the technology acceptance model. Journal of Marine Science and Engineering, 13(12), Article 2308. https://doi.org/10.3390/jmse13122308

Kim, T., Sharma, A., Bustgaard, M., Gyldensten, W. C., Nymoen, O. K., Tusher, H. M., & Nazir, S. (2021). The continuum of simulator-based maritime training and education. WMU Journal of Maritime Affairs, 20(2), 135-150. https://doi.org/10.1007/s13437-021-00242-2

Li, F., Chen, C.-H., Xu, G., Chang, D., & Khoo, L. P. (2020). Causal factors and symptoms of task-related human fatigue in vessel traffic service: A task-driven approach. Journal of Navigation, 73(6), 1340-1357. https://doi.org/10.1017/S0373463320000326

Nguyen, D., Vadaine, R., Hajduch, G., Garello, R., & Fablet, R. (2022). GeoTrackNet: A maritime anomaly detector using probabilistic neural network representation of AIS tracks and a contrario detection. IEEE Transactions on Intelligent Transportation Systems, 23(6), 5655-5667. https://doi.org/10.1109/TITS.2021.3055614

Nofandi, F., Widyaningsih, U., Rakhman, R. A., Mirianto, A., Zuhri, Z., & Harini, N. V. (2022). Case study of ship traffic crowds in the Malacca Strait-Singapore by using vessel traffic system. IOP Conference Series: Earth and Environmental Science, 1081(1), Article 012009. https://doi.org/10.1088/1755-1315/1081/1/012009

Praetorius, G., Hollnagel, E., & Dahlman, J. (2015). Modelling Vessel Traffic Service to understand resilience in everyday operations. Reliability Engineering & System Safety, 141, 10-21. https://doi.org/10.1016/j.ress.2015.03.020

Priadi, A. A., Ivan, R., Darsani, & Anindhyta, C. (2024). Evaluation of the implementation of traffic separation scheme (TSS) in the Sunda Strait. IOP Conference Series: Earth and Environmental Science, 1294(1), Article 012028. https://doi.org/10.1088/1755-1315/1294/1/012028

Qu, X., Meng, Q., & Suyi, L. (2011). Ship collision risk assessment for the Singapore Strait. Accident Analysis & Prevention, 43(6), 2030-2036. https://doi.org/10.1016/j.aap.2011.05.022

Relling, T., Lutzhoft, M., Ostnes, R., & Hildre, H. P. (2021). The contribution of Vessel Traffic Services to safe coexistence between automated and conventional vessels. Maritime Policy & Management, 49(7), 990-1009. https://doi.org/10.1080/03088839.2021.1937739

Rong, H., Teixeira, A. P., & Guedes Soares, C. (2020). Data mining approach to shipping route characterization and anomaly detection based on AIS data.

Ocean Engineering, 198, Article 106936. https://doi.org/10.1016/j.oceaneng.2020.106936

Sharma, A., Mallam, S., MacKinnon, S. N., & Saetrevik, B. (2025). A systematic review of cognitive and social factors in vessel traffic services operations. Transport Reviews, 46(2), 322-343. https://doi.org/10.1080/01441647.2025.2569578

Sharma, A., Nazir, S., & Ernstsen, J. (2019). Situation awareness information requirements for maritime navigation: A goal directed task analysis. Safety Science, 120, 745-752. https://doi.org/10.1016/j.ssci.2019.08.016

Sobaruddin, D. P., Armawi, A., & Giyarsih, S. R. (2026). The development of inshore traffic zone in Sunda Strait. Indonesian Journal of Geography, 58(1), 102-117. https://doi.org/10.22146/ijg.115071

Soldi, G., Gaglione, D., Forti, N., De Simone, A., Daffina, F. C., Bottini, G., Quattrociocchi, D., Millefiori, L. M., Braca, P., Carniel, S., Willett, P., Iodice, A., Riccio, D., & Farina, A. (2021). Space-based global maritime surveillance. Part I: Satellite technologies. IEEE Aerospace and Electronic Systems Magazine, 36(9), 8-28. https://doi.org/10.1109/MAES.2021.3070862

Sunaryo, S., Priadi, A. A., & Tjahjono, T. (2015). Implementation of traffic separation scheme for preventing accidents on the Sunda Strait. International Journal of Technology, 6(6), 990-997. https://doi.org/10.14716/ijtech.v6i6.1966

Svanberg, M., Santen, V., Horteborn, A., Holm, H., & Finnsgard, C. (2019). AIS in maritime research. Marine Policy, 106, Article 103520. https://doi.org/10.1016/j.marpol.2019.103520

Tu, E., Zhang, G., Rachmawati, L., Rajabally, E., & Huang, G.-B. (2018). Exploiting AIS data for intelligent maritime navigation: A comprehensive survey from data to methodology. IEEE Transactions on Intelligent Transportation Systems, 19(5), 1559-1582. https://doi.org/10.1109/TITS.2017.2724551

van de Merwe, K., Mallam, S., & Nazir, S. (2022). Agent transparency, situation awareness, mental workload, and operator performance: A systematic literature review. Human Factors, 66(1), 180-208. https://doi.org/10.1177/00187208221077804

Weintrit, A. (2013). Prioritized main potential solutions for the e-Navigation concept. TransNav: International Journal on Marine Navigation and Safety of Sea Transportation, 7(2), 27-38. https://doi.org/10.12716/1001.07.01.03

Wolsing, K., Roepert, L., Bauer, J., & Wehrle, K. (2022). Anomaly detection in maritime AIS tracks: A review of recent approaches. Journal of Marine Science and Engineering, 10(1), Article 112. https://doi.org/10.3390/jmse10010112

Yan, Z., Xiao, Y., Cheng, L., He, R., Ruan, X., Zhou, X., Li, M., & Bin, R. (2020). Exploring AIS data for intelligent maritime routes extraction. Applied Ocean Research, 101, Article 102271. https://doi.org/10.1016/j.apor.2020.102271

Yang, D., Wu, L., Wang, S., Jia, H., & Li, K. X. (2019). How big data enriches maritime research: A critical review of Automatic Identification System

(AIS) data applications. Transport Reviews, 39(6), 755-773. https://doi.org/10.1080/01441647.2019.1649315

Zaman, M. B., Kobayashi, E., & Zubaydi, A. (2021). Traffic analysis for enhancing safety in the Singapore Straits using AIS data. IOP Conference Series: Earth and Environmental Science, 649(1), Article 012065. https://doi.org/10.1088/1755-1315/649/1/012065

Zhang, L., & Meng, Q. (2019). Probabilistic ship domain with applications to ship collision risk assessment. Ocean Engineering, 186, Article 106130. https://doi.org/10.1016/j.oceaneng.2019.106130

Zhang, W., Goerlandt, F., Kujala, P., & Wang, Y. (2016). An advanced method for detecting possible near miss ship collisions from AIS data. Ocean Engineering, 124, 141-156. https://doi.org/10.1016/j.oceaneng.2016.07.059

Zhao, L., & Shi, G. (2019). Maritime anomaly detection using density-based clustering and recurrent neural network. Journal of Navigation, 72(4), 894-916. https://doi.org/10.1017/S0373463319000031

Zhen, R., Riveiro, M., & Jin, Y. (2017). A novel analytic framework of real-time multi-vessel collision risk assessment for maritime traffic surveillance. Ocean Engineering, 145, 492-501. https://doi.org/10.1016/j.oceaneng.2017.09.015