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THE SAFE VOYAGE FALLACY: DIGITAL TWINS, PREDICTIVE RISK, AND THE FUTURE OF MARITIME RESPONSIBILITY

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A digital twin onboard a vessel detects abnormal hull stress and predicts an 82% probability of structural failure within the next seventy-two hours[1]. The warning is acknowledged but ultimately disregarded as not urgent by the captain . The vessel completes its voyage without incident and no damage is sustained.

Has anything legally wrong occurred?

Traditionally, maritime law would advocate that The absence of harm leaves little room for liability. Meanwhile in the new tech age , the emergence of digital twins ,virtual replicas capable of continuously analysing operational data and forecasting risks before they materialise[2],forces a reconsideration of this assumption. The question is no longer whether a ship has suffered damage, but whether a decision made in the face of credible predictive knowledge, can remain legally invisible simply because the sea chose not to punish it.

For centuries, maritime law has been concerned with the seafarer's response to danger. International conventions such as the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)[3]and the International Regulations for Preventing Collisions at Sea (COLREGs)[4] have been built around the idea that competent mariners identify risks, exercise professional judgment, and take appropriate action. Implicit within this framework is a simple sequence: a danger emerges, a seafarer perceives it, and the law evaluates the reasonableness of the response. This framework relies heavily on an officer’s situational judgment and experienced knowledge of the vessel , but what happens when the machine consistently demonstrates better foresight than the competent officer?

1. DNV, *Maritime Forecast to 2050: Technology Outlook 2050* 76–81 (2023)
2. Int'l Ass'n of Classification Societies, *Digital Twins in Shipping: Emerging Applications and Regulatory Considerations* 4–9 (2023).
3. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, July 7, 1978, 1361 U.N.T.S. 2.
4. Convention on the International Regulations for Preventing Collisions at Sea, Oct. 20, 1972, 1050 U.N.T.S. 16.

Digital twins disrupt this sequence by introducing a new category of information: predictive knowledge. Unlike radar, or visual lookout systems, revealing existing conditions, digital twins forecast future conditions by analysing real-time operational data and identifying risks before they become observable. This development becomes particularly significant when viewed alongside Rule 7 of the COLREGs, which requires every vessel to use "all available means appropriate to the prevailing circumstances and conditions" [5]to determine whether a risk of collision exists. Historically, technological innovations such as AIS, and ECDIS gradually evolved from novel navigational aids into tools that courts, regulators, and mariners increasingly regarded as part of the "available means"[6] expected of prudent navigation. Digital twins may represent the next stage in that evolution. Yet unlike their predecessors, they do not merely detect danger,they predict it. Consequently, they raise a difficult question: if technology can identify a risk before it is perceptible to human operators, can that risk become legally relevant before it becomes physically observable?

This issue becomes significant when viewed through the lens of foreseeability, a cornerstone of negligence law[7]. Traditionally, foreseeability has been assessed according to what a reasonable person could have anticipated in the circumstances. Maritime negligence has similarly relied upon the standard of the reasonable and competent seafarer[8]. However, if a digital twin can predict structural failures, navigational hazards, or machinery breakdowns that can not be independently detectable by human operators, whose foresight should the law recognise?

The answer cannot simply be that machines replace human judgment. STCW firmly preserves the central role of the master and officers[9], placing competence, situational awareness, and independent decision-making squarely within the realm of human responsibility. Likewise, the COLREGs impose obligations upon navigators rather than technologies.

5. Convention on the International Regulations for Preventing Collisions at Sea art. 7, Oct. 20, 1972, 1050 U.N.T.S. 16.
6. Nicholas J. Healy & Joseph C. Sweeney, *The Law of Marine Collision* § 7-5 (1998).
7. *Overseas Tankship (U.K.) Ltd. v. Morts Dock & Eng'g Co. (The Wagon Mound No. 1)*, [1961] A.C. 388 (P.C.).
8. *Blyth v. Birmingham Waterworks Co.*, (1856) 11 Ex. Ch. 781.
9. International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, July 7, 1978, 1361 U.N.T.S. 2.

Rule 7 creates a doctrinal tension with the Rule 2 , reinforcing the enduring obligation of good seamanship[10]. Yet neither instrument was drafted with predictive technologies in mind. While they clearly establish who remains responsible, they are less certain about how responsibility should be assessed when a machine can identify risks that are not yet perceptible to the human eye. The challenge, therefore, is not one of authority, but of accountability in an era of enhanced foresight...

At first glance, one might argue that digital twin warnings should simply be followed. Such a proposition, however, would be both impractical and inconsistent with maritime practice. Ships do not operate in controlled laboratory environments. Masters routinely navigate competing considerations, including weather conditions, vessel characteristics, traffic density, crew limitations, commercial obligations, and operational realities. Moreover, predictive systems are not infallible[11]. False positives, sensor inaccuracies, and incomplete datasets remain genuine concerns.in such cases, relying blindly on a set of algorithmic data without reasonable judgement would render the foundation of STCW baseless, which essentially focuses om judgement rather than obedience.

A competent officer is expected to evaluate information critically, not surrender decision-making to automated systems. Blind reliance upon a digital twin may be just as problematic as blindly ignoring it.Nevertheless, the existence of uncertainty does not render predictive warnings legally irrelevant. Maritime law has never required certainty before action. Vessels alter course based on anticipated collision risks, reduce speed in restricted visibility, and investigate engineering anomalies long before damage becomes inevitable. The law is fundamentally concerned with prudence in the face of risk, not certainty in the face of harm[12].

As digital twins become increasingly sophisticated, tested, and integrated into maritime operations, their warnings may acquire a significance similar to that of earlier navigational technologies. Radar, AIS, and ECDIS were once novel innovations[13]

10. Convention on the International Regulations for Preventing Collisions at Sea art. 2, Oct. 20, 1972, 1050 U.N.T.S. 16.
11. Barış Soyer & Andrew Tettenborn eds., *New Technologies, Artificial Intelligence and Shipping Law in the Twenty-First Century* 84–89 (2021).
12. *The Wagon Mound No. 1*, [1961] A.C. 388 (P.C.).
13. Erik Røsæg, Autonomous Ships and the Law, 49 J. Mar. L. & Com. 343, 352–56 (2018).

Over time, as their reliability and industry acceptance increased, courts and regulators began treating the failure to properly utilise them as evidence of poor seamanship or negligence. A similar trajectory may emerge for predictive technologies.

The more intriguing legal question, however, arises where no accident occurs at all. If a credible warning is ignored but the voyage concludes safely, should maritime law remain indifferent? Traditional negligence law would likely answer yes, since liability generally requires proof of damage[14]. Yet maritime regulation has never been exclusively concerned with harmful outcomes. Port State Control inspections, certification requirements, and safety management systems frequently address unsafe conduct before accidents occur.[15,16]

Digital twins introduce a new dimension to this preventive approach. Historically, ignorance could be difficult to disprove. A seafarer could plausibly argue that a risk was unknown or unforeseeable. Predictive systems change this dynamic by creating detailed records of what was known, when it was known, and how decision-makers responded[17]. The legal significance of digital twins may therefore lie less in their predictive accuracy and more in their ability to document decision-making processes.

This development raises a profound possibility. Maritime law has traditionally scrutinised accidents to determine whether poor decisions occurred. Predictive technologies may gradually encourage scrutiny of poor decisions even where accidents never materialise. In other words, the focus may shift from outcomes to decision quality[18].

Such a transformation does not advocates the argument for automatic liability whenever a warning is ignored. Neither it diminish the importance of human judgment. Rather, it suggests that increasingly reliable predictive systems may influence how courts, regulators, and investigators assess the reasonableness of conduct in the face of foreseeable risk[19].

14. W. Page Keeton et al., *Prosser and Keeton on the Law of Torts* § 30, at 165–66 (5th ed. 1984).
15. International Convention for the Safety of Life at Sea, Nov. 1, 1974, 1184 U.N.T.S. 278.
16. Int'l Maritime Org., *International Safety Management Code* (ISM Code), incorporated through SOLAS ch. IX.
17. Int'l Maritime Org., Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), MSC.1/Circ.1638, at 7–12 (June 3, 2021).
18. Henrik Ringbom, Regulating Autonomous Ships—Concepts, Challenges and Precedents, 29 Ocean Y.B. 399, 421–27 (2015).
19. Barış Soyer & Andrew Tettenborn eds., *New Technologies, Artificial Intelligence and Shipping Law in the Twenty-First Century* 105–11 (2021).

The basic doubt , therefore, is not whether digital twins can replace seafarers. They cannot. Rather the significant question is whether enhanced foresight should create enhanced responsibility. If technology enables mariners to anticipate dangers earlier and with greater precision than ever before, should the law continue to judge them solely according to traditional standards of knowledge and competence?

Returning to the opening scenario, the vessel arrived safely. Yet, a verified warning was ignored. Was the master acting with prudent discretion, benefiting from blind luck, or displaying a lapse in professional responsibility? Digital twins challenge our traditional, outcome-based approach by making risks visible before they materialize and human choices reviewable before disaster strikes. The future of maritime law may depend not merely on determining who caused a casualty, but on redefining what it means to be a prudent seafarer when a machine sees the danger first[20].

20. Henrik Ringbom, Regulating Autonomous Ships—Concepts, Challenges and Precedents, 29 Ocean Y.B. 399, 425–28 (2015); Erik Røsæg, Autonomous Ships and the Law, 49 J. Mar. L. & Com. 343, 370–74 (2018).

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