Input paper for the following Committee(s): check as appropriate

□ ARM □ ENG □ PAP

□ ENAV **X** DTEC

Purpose of paper:

□ Input

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Agenda item [1]

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Large Language Models Technology to Support VTS Post-Event Analysis of Collisions and Near-Misses

1. INTRODUCTION

Maritime collision and near-miss incidents provide valuable insights for understanding how navigational risks develop and identifying lessons learnt to prevent recurrences. However, extracting actionable lessons from reported or detected cases requires evidence from multiple sources to be collected, aligned and interpreted, a process that remains largely manual and resource-intensive.

At DTEC5, A*STAR and MPA presented on the challenges of conducting post-incident analysis of collisions and near-misses today, as well as the potential of Large Language Models (LLMs) to address these challenges. LLMs are an emerging form of Artificial Intelligence capable of processing, organising and interpreting large volumes of structured and unstructured information, offering new possibilities for supporting such analytical tasks. Our research has demonstrated that LLMs possess significant potential to be integrated into Vessel Traffic Services (VTS) operations, particularly for post-incident and near-miss event analysis.

2. PURPOSE

Noting the existing IALA guideline G1118 “Marine Casualty – Incident Reporting and Recording Including Near-miss Situations” where it describes how VTS authorities handle, record, and report post-vessel collisions and near misses, this information paper:

- proposes an LLM-assisted, human-in-the-loop framework for integrating LLM capabilities into VTS collision incidents and near-miss events analysis;
- suggests an approach to improving analytical efficiency, strengthening the consistency and evidentiary support of case conclusions, and converting verified cases into digital, standardised and reusable safety-learning outputs; and
- highlights the need for a deep dive into whether LLMs represent a viable technology for adoption in VTS operations
- considers a role for IALA to provide timely guidance to facilitate the wider adoption of LLMs across the maritime community for better safety of navigation and operation efficiencies.

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3. LLM-ASSISTED, HUMAN-IN-THE-LOOP FRAMEWORK

To overcome the bottlenecks of manual investigation, a framework is proposed that leverages the advanced capabilities of LLMs to support maritime post-event analysis. LLMs excel at processing heterogeneous data sources, such as unstructured voice communication transcripts, voyage notes, and complex logs, rapidly extracting semantic meaning, aligning timelines, and drafting structured event syntheses. By combining LLM-enabled automation with staged maritime expert oversight, a proposed framework with a post-event analysis system would significantly reduce the manual effort required to integrate multi-source evidence, reconstruct dynamic events and prepare structured and standardized case information, while keeping analytical reasoning transparent.

Operationally, the framework would separate evidence preparation and event reconstruction from higher-level interpretation and assessment. LLMs assist in parsing and structuring fragmented data into a cohesive preliminary timeline. Maritime domain experts then verify and correct the reconstructed case information. Once validated, the data is systematically analysed against applicable regulations (such as COLREGs), vessel-performance characteristics, and historical case repositories. Human experts retain ultimate responsibility for reviewing and finalizing all analytical conclusions. The overall workflow is illustrated in Figure 1.

Once a case is identified, the workflow proceeds through the following stages:

Evidence-quality and case-validity assessment: The LLM-enabled system assesses the quality, completeness and consistency of the available evidence, including AIS replay, VHF audio, VTS records and incident reports. Data limitations and their potential impact on subsequent analysis and human review are clearly identified.

Multi-source event reconstruction: Vessel particulars, movements, manoeuvring actions, VHF communications, VTS interventions, traffic context and environmental conditions are aligned and integrated into a structured event timeline and standardised case summary.

Expert verification and correction: Maritime experts review the evidence assessment and reconstructed timeline, verify the information against the source data, and correct any errors, gaps or misinterpretations before further analysis.

Knowledge-supported LLM analysis: The verified case information is analysed together with applicable regulations, operational procedures, vessel-performance data and historical encounter records. The system compares the case with similar events, recurring encounter patterns, risk profiles and traffic hotspots. It then identifies potential root causes, contributing factors and unresolved questions, assesses whether the case should be retained as a near-miss incident, estimates its severity, and provides evidence-linked reasoning for expert consideration.

Expert finalisation and structured output: Maritime experts review and revise the analytical results, interpret the operational context, and approve the final conclusions, safety lessons and preventive recommendations. The approved findings, supporting evidence, reasoning and classification results are documented in a standardised case-analysis report and stored as a structured case record for future analysis and safety learning.

Throughout the workflow, the LLM serves as a digital analytical assistant, while maritime experts remain responsible for evidence validation, professional interpretation and final decision-making. The framework is intended to support, rather than replace, professional judgement, formal accident investigation or accountable decision-making.

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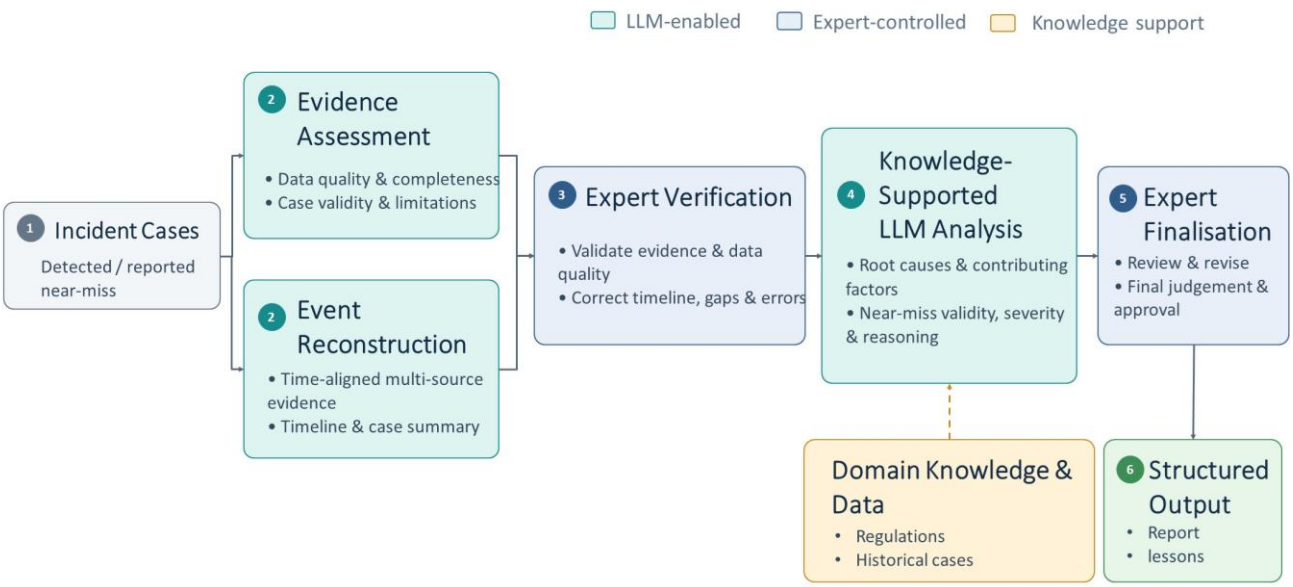

Figure 1 LLM-ASSISTED POST-EVENT ANALYTICS FRAMEWORK

4. VALUE FOR LLM-ASSISTED POST-EVENT ANALYSIS AND SAFETY LEARNING

The principal value of the proposed LLM-assisted framework lies in its capacity to dramatically enhance the efficiency, scalability, and depth of maritime post-event analysis. For example, drawing on experience gained from developing a Singapore prototype LLM-assisted post-event analysis system, a case investigation that would typically take several days could be substantially accelerated and completed within hours through human–AI collaboration enabled by the proposed framework. By using LLMs to harmonize multi-source evidence, such as transcribing communications, structuring voyage notes, extracting key navigational markers, and generating coherent event timelines, the framework can substantially reduce the time and specialist effort required for routine case review and reconstruction. Consequently, VTS Authorities and stakeholders can investigate and review a broader spectrum of collision and near-miss incidents in a systematic, timely, and scalable manner in a more systematic, scalable and timely manner.

Beyond administrative efficiency, LLMs foster more data-informed analytical conclusions by aligning vessel movements, proximity indicators, communications and operational actions within a unified timeline. When combined with vessel-performance characteristics, regulatory standards (e.g. COLREGs) and comparable historical precedents, the LLM-based system can help better generate evidence-linked assessments detailing how encounters develop, identifying contributing factors and refining near-miss classification and learning insights. This establishes and improves the consistency, transparency and explainability of the analytical process, while maritime experts remain responsible for verifying the evidence, correcting AI outputs and approving the final conclusions.

Ultimately, the resulting structured and expert-validated repository serves as a powerful digital asset for operational review, procedure improvement and continuous training for VTS operators, pilots and mariners. Over time, an accumulated case base of this scale may unlock advanced capabilities of VTS and vessel navigation, such as timely, LLM-assisted timely pattern identification for recurring navigational risk and traffic risk hotspots, while providing feedback for improving automated near-miss detection, risk-warning and hotspot-identification models.

5. RECOMMENDATION

To accelerate the adoption of LLM technology in VTS operations, IALA is well-positioned to play a pivotal role in steering and facilitating this process in the interest of improving the safety of navigation and operational efficiency. To this end, we recommend that IALA consider developing new guidelines or updating existing ones (e.g. G1118) on the adoption of LLM technology for VTS operational use cases, to better support the technology adoption in the maritime community.

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6. REFERENCES

[1] A*STAR and MPA, Large Language Models (LLMs) for Next-Generation Vessel Traffic Services (VTS): Applications and Opportunities, DTEC 5 information paper.

[2] A*STAR and MPA, Essential Practices for Data and Management in Developing Automated Near-Miss Incident Identification, DTEC 3 information paper.

[3] G1118 Marine Casualty – Incident Reporting and Recording Including Near-miss Situations as It Relates to VTS

7. ACTION REQUESTED OF THE COMMITTEE

DTEC is invited to:

1 consider the applicability and usefulness of the proposed LLM-assisted, human-in-the-loop framework;

2 consider the potential of adopting LLM technology for VTS operations to improve analytical efficiency, consistency and data-supported decision-making, while maintaining expert oversight and appropriate safeguards; and

3 consider how IALA could provide timely guidance to facilitate the wider adoption of LLMs across the maritime community for the safety of navigation and operation efficiency.

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