



SMRC x MTEC/ICMASS CONFERENCE 2026

Smart Ships. Secure Seas. Sustainable Futures.

Conference Proceedings

Organisers:



In Collaboration with:



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Welcome Message

Welcome to the SMRC x MTEC/ICMASS Conference 2026!


Themed “Smart Ships. Secure Seas. Sustainable Futures.”, the SMRC x MTEC/ICMASS Conference 2026 will be held in Singapore from 22 to 23 April 2026. The event is jointly organised by the Singapore Maritime Institute, Maritime and Port Authority of Singapore, SINTEF Ocean, Norwegian University of Science and Technology, in collaboration with The Norwegian Forum for Autonomous Ships and the International Network for Autonomous Ships.

One of the key maritime research and technology events during Singapore Maritime Week 2026, the conference connects global thought leaders from academia and industry to present cutting-edge advancements in maritime technology, autonomous shipping, and port operations.

This year’s conference topics include:

Maritime Energy

- Alternative Energy – Molecules & Electrons
- Port Energy Infrastructure
- Regulatory & Economic Aspects



Cargo Optimisation

- Cargo Handling Efficiency
- Intermodal Connectivity
- Digitalisation & Data Analytics



Smart Ships

- Autonomous Shipping Technologies
- Connectivity & Data Exchange
- Predictive Maintenance
- Bridge Systems & Human-Machine Interface



Maritime Cybersecurity

- Vessel Systems Security
- Communication Security
- Operational Technology (OT) Security
- Crew Training and Awareness



The key objectives of the conference include:

- **Advance frontier maritime research and innovation** by showcasing cutting-edge developments in decarbonisation, digitalisation, autonomy, and cybersecurity across ship, port and logistics systems.
- **Strengthen international research and industry collaboration** by convening academia, policymakers, technology developers, and practitioners to co create solutions to shared maritime challenges.
- **Bridge research and deployment** by translating scientific advances into scalable, real-world applications that enhance safety, efficiency, and environmental performance across the maritime value chain.
- **Develop maritime talent and capabilities** by inspiring researchers, engineers, and practitioners to pursue interdisciplinary innovation in next-generation maritime systems.

A conference of this scale can only succeed through a collective effort. We would like to express our sincere thanks to the Organising and Steering Committee Members, as well as the Reviewers for reviewing the papers and their invaluable input and advice.

Organising Committee

- Conference Manager – Mr Loh Yee Wei (Singapore Maritime Institute)
- Conference Manager – Mr Ang Yan Koon (Maritime & Port Authority of Singapore)

Steering Committee

- Thomas Ting, Director (Technology & Innovation) / Chief Digital Officer, MPA
- Dr. Chen Winwei, Deputy Executive Director, SMI
- Prof. Chan Eng Soon, Chief Executive Officer, TCOMS
- Prof. Jason Xu, Centre Director, MESD, Nanyang Technological University
- Prof. Ng Szu Hui, Head of Department of Industrial Systems Engineering & Management, National University of Singapore
- Dr. Aziz Merchant, Executive Vice President (Engineering), Seatrrium
- Kjell Røang, Senior Advisor, The Research Council of Norway
- Bjørn Simonsen, Science and Technology Counsellor, Innovation Norway
- Arne Fredheim, Research Director, SINTEF Ocean
- Kay Endre Fjørtoft, Research Manager, SINTEF Ocean
- Ørnulf Jan Rødseth, General Manager, NFAS
- Prof. Sverre Steen, Head of Department of Marine Technology, NTNU

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22 APR 2026 CONFERENCE DAY 1 PROGRAMME

22 APR 2026 CONFERENCE DAY 1 PROGRAMME	
Time	Programme
8.30am - 10.00am	<p>Conference Registration Morning Coffee and Tea</p> <p>Venue: Suntec Singapore Convention & Exhibition Centre Level 3, Summit 2 (Foyer)</p>
10.00am – 10.10am	<p>Opening Address Professor Low Teck Seng Chairman, Singapore Maritime Institute</p>
10.10am – 10.30am	<p>Plenary Talk 1: Quantum Computing in the Maritime Sector: Overhyped or a real Game Changer? Professor Carlos Jahn Head, Institute of Maritime Logistics, Hamburg University of Technology Director, Fraunhofer Center for Maritime Logistics and Services</p>
10.30am – 10.50am	<p>Plenary Talk 2: MODE - Industry-Academia Collaboration for Developing a Simulation Platform to Build Sustainable Maritime Transport Systems Professor Hideaki Murayama Professor, Department of Systems Innovation, School of Engineering, The University of Tokyo Project Professor, Maritime and Ocean Digital Engineering Laboratory (MODE)</p>
10.50am – 11.10am	<p>Plenary Talk 3: Pervasive Connectivity for Real-Time and Embodied Intelligence: Powering the Next Frontier of Maritime Transformation Dr. Sun Sumei Executive Director, A*STAR Institute for Infocomm Research (A*STAR I²R)</p>

22 APR 2026 CONFERENCE DAY 1 PROGRAMME		
Time	Programme	
11.10am – 11.20am	<p>Special Address Mr Even Tronstad Sagebakken State Secretary, Norwegian Ministry of Trade, Industry and Fisheries</p>	
11.20am – 1.00pm	<p>Networking Lunch and Research Poster Showcase</p>	
1.00pm – 3.00pm	<p>Parallel Session 1: Smart Ships <i>Venue: Summit 2, Level 3</i> <i>Session Chair: Dr Liang Hui, Technology Centre for Offshore and Marine, Singapore (TCOMS)</i></p>	<p>Parallel Session 2: Maritime Energy <i>Venue: Room 331, Level 3</i> <i>Session Chair: Prof Jason Xu, School of Materials Science and Engineering, Nanyang Technological University (NTU)</i></p>
	<p>Addressing Challenges in Autonomous Shipping: Insights from a Singapore Pilot Project and the Emerging Role of Agentic AI <i>Bernad Peter Francis, Seatrium Technology and Innovation</i></p>	<p>Opportunities and Challenges for Maritime Nuclear <i>Michael Bluck, Imperial College</i></p>
	<p>Simulation-Based Validation of Autonomous Navigation System in Singapore Waters <i>Tomoaki Yamada, ClassNK</i></p>	<p>A Case Study of Full-Electric Pilot Launch – From Ship Design, Operations Optimisation, to Fleet Charging Demand Estimation <i>Tay Chuan Beng, Singapore Institute of Technology (SIT)</i></p>

22 APR 2026 CONFERENCE DAY 1 PROGRAMME		
Time	Programme	
1.00pm – 3.00pm	<p>Application of Model-Based System Engineering to Maritime Autonomy <i>Liza Chua and Robert Ong, American Bureau of Shipping (ABS) and INCOSE ESEP</i></p>	<p>Assessing the Environmental Impacts of Alternative Fuels: A Fugitive Emission Study <i>He Zhengxin, Maritime Energy and Sustainable Development Centre of Excellence, Nanyang Technological University (MESD, NTU)</i></p>
	<p>Enabling Safe and Scalable Autonomous Shipping in Congested Maritime Environments <i>Aranya Mitra, MarineAI Ltd Plymouth</i></p>	<p>Mitigation of Ammonia Leaks during Bunkering Operations using Water Curtains - A CFD Study <i>Lau Yang Hao, A*STAR Institute of High Performance Computing (A*STAR IHPC)</i></p>
	<p>Formal descriptions of MASS Operational Envelope and Operational Design Domain <i>Ørnulf Jan Rødseth, ITS Norway</i></p>	<p>Mitigation of Ammonia Loss of Containment (LOC) During Bunkering Using an Air Curtain <i>Anthony B. Hamzah, Maritime Energy and Sustainable Development Centre of Excellence, Nanyang Technological University (MESD, NTU)</i></p>
	<p>“How do I trust my computer vision system” The role of Assurance in supporting a thriving Maritime Autonomy sector <i>Andre Burgess, National Physical Lab</i></p>	<p>Two-Phase Ammonia Flowmeter Performance Verification System <i>Ye Shaochun, A*STAR National Metrology Centre (NMC)</i></p>

22 APR 2026 CONFERENCE DAY 1 PROGRAMME		
Time	Programme	
1.00pm – 3.00pm	Efficient Data Association and Hypothesis Management for Multiple Extended Object Tracking in Maritime Applications <i>Martin Baerveldt, Norwegian University of Science and Technology (NTNU)</i>	
	Maritime Autonomy and its Impact on European Shipping <i>Christoph Burmeister, Fraunhofer Center for Maritime Logistics and Services CM</i>	
3.00pm – 3.20pm	Coffee/Tea Break	
3.20pm – 5.20pm	Parallel Session 3: Smart Ships <i>Venue: Summit 2, Level 3</i> <i>Session Chair: Assoc Prof Bernard How, Singapore Institute of Technology (SIT)</i>	Parallel Session 4: Maritime Cybersecurity <i>Venue: Room 331, Level 3</i> <i>Session Chair: Dr Harishma Boyapally, iTrust, Singapore University of Technology and Design (iTrust, SUTD)</i>
	Towards a Maritime RF Digital Twin for Predictive Connectivity and Autonomous Ship Operations in Singapore Waters <i>Hoang Anh Tuan, A*STAR</i>	Resilient Maritime Localisation Using 5G Non-Terrestrial Networks Against GNSS Spoofing and Jamming <i>Ma Yugang, A*STAR Institute for Infocomm Research (A*STAR I²R)</i>

22 APR 2026 CONFERENCE DAY 1 PROGRAMME		
Time	Programme	
3.20pm – 5.20pm	<p>Virtual Testing for MASS: A Comprehensive Review of Current Practices, Gaps, and Standardisation Needs <i>Ten Yao Hua, American Bureau of Shipping (ABS)</i></p>	<p>StormShield: A Semi-Markov-Driven Defense Against DDoS Attacks in NMEA 2000 Maritime IoT Systems <i>Kamel Abbad, Navette Electrique Autonome Connectée (NEAC) Industry</i></p>
	<p>Development of a Mathematical Manoeuvring Model toward Constructing a Safety Assessment Environment for MASS <i>Makoto Ito, ClassNK</i></p>	<p>Navigating the Gaps: Understanding AIS Data Reliability — A Big Data Framework for Analysing Missing Patterns <i>Zhao Liangbin, A*STAR</i></p>
	<p>A Robust Simulation Framework for Verification and Validation of Autonomous Maritime Navigation <i>Mayur Shivaji Patil, Texas A&M University</i></p>	<p>Simulator-Based Visualisation of Cyberattack Effects for Maritime Cybersecurity Training <i>Gayatri Kumar Tota, Singapore Polytechnic</i></p>
	<p>Situation Awareness Through Shared Control: Safety-Assisted Remote Maritime Operations <i>Andreas Gudahl Tufte, Norwegian University of Science and Technology (NTNU)</i></p>	<p>Cyber Attacks Against Remote Operations Centres: Risks and Legal Implications <i>Fatih Durmaz, University of Southampton</i></p>

22 APR 2026 CONFERENCE DAY 1 PROGRAMME		
Time	Programme	
3.20pm – 5.20pm	Visual Rule-Guided Deep Reinforcement Learning for Autonomous Ship Navigation in IALA-Regulated Port Environments <i>Liu Yuqing, Nanyang Technological University (NTU)</i>	Multilink Connectivity Framework for Seamless Switch-over <i>Goh Lee Kee, A*STAR</i>
	A Web-Based Virtual Test Environment for Autonomous Navigation Systems Validation <i>Daniel Liu, Technology Centre for Offshore and Marine, Singapore (TCOMS)</i>	Modeling and Engineering Cyber-Safety Causality in Autonomous Maritime Navigation <i>Sinem Getir Yaman, University of York</i>
		On the Development of Scalable and Modular Ka-band SATCOM Terminal for Tropical Ocean <i>Qing Xianming, A*STAR</i>
5.20pm	End of Day 1 Conference	

23 APR 2026 CONFERENCE DAY 2 PROGRAMME

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
8.00am - 9.00am	Conference Registration	
9.00am – 10.15am	Parallel Session 5: Smart Ships <i>Venue: Summit 2, Level 3</i> <i>Session Chair: Dr Liang Hui, Technology Centre for Offshore and Marine, Singapore (TCOMS)</i>	Parallel Session 6: Cargo Optimisation <i>Venue: Room 331, Level 3</i> <i>Session Chair: Prof Ng Szu Hui, Department of Industrial Systems Engineering & Management, National University of Singapore (NUS)</i>
	From CONOPS to approval: Regulatory and commercial pathways for demonstrating autonomous inland shipping between Terneuzen and Ghent <i>Odd Erik Mørkrid, SINTEF Ocean AS</i>	Preventing Collisions with Critical Port Infrastructure: An Incident-Driven Approach to Designing a Shore-Based Assistance System <i>Sebastian Feuerstack, German Aerospace Center</i>
	Agent-Based Multimodal Retrieval and Regulation Analysis for Automated Ship Design Compliance <i>Yi-Lun Huang, National Taiwan Ocean University</i>	Working Together Is Success: Human-Machine Teaming to Increase the Use of Calculated Shipping Routes to Reduce Emissions <i>Adam Sobey, University of Southampton</i>

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
9.00am – 10.15am	<p>Adaptive Design and Operations for Next-Generation Ships under Uncertainty via the MODE Simulation Platform <i>Takuya Nakashima, The University of Tokyo</i></p>	<p>MARKS: An AI-Driven Maritime Risk Knowledge System (MARKS) for Disruption Event Profiling and Supply Chain Impact Projection <i>Wang Ke, A*STAR Institute of High Performance Computing (A*STAR IHPC)</i></p>
	<p>Deep Reinforcement Learning Based Safety-critical Scenario Generation for Autonomous Ship Digital Testing <i>Wang Hongwei, A*STAR Institute of High Performance Computing (A*STAR IHPC)</i></p>	<p>Dynamic navigation and Port call optimisation in real time <i>Kay Endre Fjørtoft, SINTEF Ocean AS</i></p>
	<p>Turku University of Applied Sciences Testbed for Resilient Uncrewed Surface Vessels <i>Jarkko Paavola, Turku University of Applied Sciences</i></p>	<p>Integrating Agentic AI into Maritime Logistics: Towards Autonomous, Sustainable and Resilient Port Ecosystems <i>Chiara Saragani, CENIT</i></p>
	<p>Parallel Session 7*: SMU Maritime Thought Leadership: Stakeholder Integration – towards a future maritime ecosystem empowered by AI <i>(Session 7 ends at 12.30pm)</i></p>	
10.15am – 10.30am	Coffee/Tea Break	

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
10.30am – 11.45am	Parallel Session 8: Smart Ships <i>Venue: Summit 2, Level 3</i> <i>Session Chair: Capt Savio Coutinho, Singapore Maritime Academy, Singapore Polytechnic</i>	Parallel Session 9: Cargo Optimisation <i>Venue: Room 331, Level 3</i> <i>Session Chair: Dr Fu Xiuju, A*STAR Institute of High Performance Computing (A*STAR IHPC)</i>
	Situation Awareness by Design: Consensus-Based Interface Design for Maritime Teleoperation <i>Alexey Gusev, Norwegian University of Science and Technology (NTNU)</i>	The Pulse of Maritime AI: Recent Developments, Sector Implications and Ongoing Research <i>Panagiotis Angeloudis, Imperial College</i>
	Considering the Intended Behaviour in Evaluating the Rule Compliance of MASS <i>Nina Wetzig, German Aerospace Center</i>	Automated Cargo Allocation for Maritime Tankers: Hybrid Optimisation and ML for Efficiency and Safety <i>Tan Peng Hui, A*STAR</i>
	Computer Vision Based Early Detection of Container Loss at Sea <i>Vishakha Lall, Centre of Excellence in Maritime Safety, Singapore Polytechnic (CEMS, SP)</i>	AI-Enabled Metocean Intelligence for Safe and Efficient Maritime Operations <i>Ruoying He, North Carolina State University</i>

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
10.30am – 11.45am	Formal Specification of COLREG Steering and Sailing Rules <i>Bernd Westphal, German Aerospace Center</i>	Programmable 5G Network for Enabling Smart Port Operation <i>Gary Lee, A*STAR</i>
	Study on Emergency Collision Avoidance for Autonomous Ships <i>Li Meng Xuan, National Taiwan Ocean University</i>	Joint Arrival Scheduling and Fuel-efficient Control for Smart Ships with Multi-agent Reinforcement Learning <i>Yang Xun, Nanyang Technological University (NTU)</i>
11.45am - 12.30pm	Research Poster Competition Pitching	
12.30pm – 2.00pm	Networking Lunch	
2.00pm – 3.15pm	Parallel Session 10: Smart Ships <i>Venue: Summit 2, Level 3</i> <i>Session Chair: Assoc Prof Bernard How, Singapore Institute of Technology (SIT)</i>	Parallel Session 11: Cargo Optimisation <i>Venue: Room 331, Level 3</i> <i>Session Chair: Dr Li Qiaohong, Centre of Excellence in Modelling & Simulation for Next Generation Ports, National University of Singapore (C4NGP, NUS)</i>

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
2.00pm – 3.15pm	<p>Construction of HiLS Environment and Issues Organisation Corresponding Toward Certification Acquisition of Collision Avoidance System of Autonomous Ship <i>Keisuke Tanihara, MTI Co., Ltd.</i></p>	<p>Information Asymmetry in FCFS Port Queues: A Game Theoretic Analysis of “Sail Fast, Then Wait” <i>Ayato Kitadai, The University of Tokyo</i></p>
	<p>CFD-Based Analysis of Ventilation Design and Explosion Risk for Electric Harbourcraft Battery Room <i>Chong Mei Yan, Singapore Institute of Technology (SIT)</i></p>	<p>Characterising Vessel-Cable Interaction and Seabed Events Using Distributed Acoustic Sensing (DAS) for Maritime Safety Applications <i>Vuong Nhu Khue, A*STAR Institute for Infocomm Research (A*STAR I²R)</i></p>
	<p>Spatiotemporal Patterns and Predictive Risk Analysis of Maritime Accidents in UK Waters <i>Jizhou Tang, University College London, UK</i></p>	<p>Sizing for Operational Excellence: A Simulation-Driven Study of Barge Scale in Inter-Terminal Transport for Next-Generation Port Efficiency <i>Liu Mengya, Centre of Excellence in Modelling & Simulation for Next Generation Ports, National University of Singapore (C4NGP, NUS)</i></p>

23 APR 2026 CONFERENCE DAY 2 PROGRAMME		
Time	Programme	
2.00pm – 3.15pm	<p>Understanding Aerodynamic Forces and Wake Flows Around Container Stackings Through Scaled Experiments and CFD Validation <i>Bharathi Boppana, A*STAR</i></p>	<p>Towards Next Generation Port Service Intelligence: Leveraging Generative AI and Reinforcement Learning for Cruise Vessel Berthing Plan Optimisation <i>Yin Xiao Feng, A*STAR Institute of High Performance Computing (A*STAR IHPC)</i></p>
	<p>Navigating in Waves and Currents: Challenges for Ship Maneuverability and Autonomy <i>Kudupudi Ravindra Babu, Technology Centre for Offshore and Marine, Singapore (TCOMS)</i></p>	
3.15pm – 3.35pm	Tea Break	
3.35pm – 3.50pm	Announcement of winners for the Research Poster Competition	
3.50pm – 4.35pm	<p>Panel Discussion: Autonomous Technology and Research</p> <p><u>Moderator:</u> Associate Professor Tay Chuan Beng Acting Cluster Director Programme Lead for the Future Ship and System Design R&D Programme Singapore Institute of Technology</p>	

23 APR 2026 CONFERENCE DAY 2 PROGRAMME	
Time	Programme
3.50pm – 4.35pm	<p><u>Panellists:</u></p> <p>Dr Liza Chua Senior Engineer American Bureau of Shipping (ABS)</p> <p>Mr Murthy Pasumarthy Vice President (Technology) and Head Seatrium Technology and Innovation</p> <p>Mr Odd Erik Mørkrid Research Manager, Energy and Transport SINTEF Ocean AS</p> <p>Dr Nigel Koh Senior Director Technology Centre for Offshore and Marine, Singapore (TCOMS)</p>
4.35pm – 4.45pm	<p>Closing Remarks</p> <p>Mr Kay Endre Fjørtoft Senior Research Scientist SINTEF Ocean AS</p> <p>Mr Ørnulf Jan Rødseth Senior Scientist SINTEF Ocean AS</p>
4.45pm	End of Day 2 Conference
7.00pm – 10.00pm	Conference Dinner

- ❖ Programme subject to change(s)
- ❖ Details of presentation topics and speakers for the Parallel Sessions will be announced soon.

PLENARY SPEAKERS OVERVIEW

Plenary Speaker

Professor Carlos Jahn

Head, Institute of Maritime Logistics, Hamburg University of Technology

Director, Fraunhofer Center for Maritime Logistics and Services



Prof. Dr.-Ing. Carlos Jahn is head of the Institute of Maritime Logistics at Hamburg University of Technology as well as of the Fraunhofer Center for Maritime Logistics and Services in Hamburg.

At the beginning of his professional career Carlos Jahn served as a sailor and later on as an officer in the German Navy. He studied mechanical engineering at the Helmut Schmidt University in Hamburg and economics at the University of Hagen. As a research assistant at the Fraunhofer IFF Carlos Jahn obtained a doctorate at the Otto von Guericke University of Magdeburg.

Carlos Jahn held various management and staff functions in science and industry. In 2009, he accepted the offer of a full professorship at Hamburg University of Technology and was appointed head of the Institute of Maritime Logistics. The Fraunhofer Center for Maritime Logistics and Services was founded in 2010.

Among other things, he is Chairman of the German Society for Positioning and Navigation DGON e. V., a member of the Board of Trustees of Logistics-Initiative Hamburg (LIHH), Head of the "Fraunhofer Industrial Application Centre Quantum Computing Hamburg" (Fraunhofer IQHH) and member of the Scientific Advisory Board of the Federal Ministry for Transport (BMV), Berlin.

Presentation synopsis

Quantum Computing in the Maritime Sector: Overhyped or a real Game Changer?

The presentation focuses on the potential of various applications of quantum computing in the maritime sector. Selected projects will be discussed, and the question of whether and when the time is right for maritime companies and practice-oriented researchers to engage with applications of quantum computing will be explored. Finally, an answer will be sought to the question of whether quantum computing is overhyped or a real game changer.

Plenary Speaker

Professor Hideaki Murayama

Professor, Department of Systems Innovation, School of Engineering, The University of Tokyo

Project Professor, Maritime and Ocean Digital Engineering Laboratory (MODE)



Hideaki Murayama is a Professor at the School of Engineering, The University of Tokyo. He received the B.E., M.E., and Dr.Eng. degrees from the University of Tokyo (UTokyo), in 1996, 1998, and 2001, respectively. His research focuses on digital twin technologies for ships and large-scale mechanical and offshore structures. He has been leading the development of model-based digital twin frameworks that integrate sensing, simulation, and data-driven approaches for monitoring, design, and operation of complex maritime systems. His work has also centred on structural health monitoring, composite structures, and advanced sensing technologies, particularly distributed optical fiber sensors for strain and vibration measurements in large-scale structures. He currently leads the Maritime and Ocean Digital Engineering (MODE) program at the University of Tokyo, an industry–academia initiative that promotes model-based development and digital engineering approaches for the maritime sector.

Presentation synopsis

MODE - Industry-Academia Collaboration for Developing a Simulation Platform to Build Sustainable Maritime Transport Systems

Maritime transport supports approximately 80% of global trade and more than 99% of Japan’s international cargo, making it a critical infrastructure for the global economy. At the same time, the maritime sector faces major challenges, including decarbonisation, the introduction of autonomous and highly digitalised vessels, and the need to maintain productivity in increasingly complex ship design and manufacturing processes.

The University of Tokyo started the Maritime and Ocean Digital Engineering (MODE) program as an industry–academia collaboration. MODE aims to introduce and adapt Model-Based Development (MBD) and Model-Based Systems Engineering (MBSE)—methodologies widely adopted in industries such as automotive and aerospace—to the maritime domain.

The program focuses on the development of a simulation platform that enables integrated modeling and simulation across ship design, operation, and maritime transport systems. By connecting diverse stakeholders—including shipbuilders, shipping companies, equipment manufacturers, and researchers—MODE seeks to establish a collaborative digital engineering framework for the maritime industry.

This talk introduces the concept and activities of MODE, highlighting its role in building a digital engineering ecosystem for sustainable maritime transportation, accelerating collaborative activities through simulation-based design, and fostering the next generation of engineers capable of addressing complex maritime system challenges.

Plenary Speaker

Dr. Sun Sumei
Executive Director
A*STAR Institute for Infocomm Research (A*STAR I²R)



Dr. Sumei Sun is the Executive Director of A*STAR Institute for Infocomm Research (I²R), and A*STAR's Coordinating Executive Director for Hub of the Future (HOTF). She holds a joint appointment with the Singapore Institute of Technology, and an adjunct appointment with the National University of Singapore, both as a full professor.

With strong passion in industry-relevant research and technology creation, Sumei has authored and co-authored more than 400 technical papers. She is the inventor/co-inventor of over thirty patented technologies, with most of them licensed to industry. She's a Fellow of the Academy of Engineering Singapore (SAEng), Fellow of the IEEE, AI Industry Alliance (AIIA), and Asia-Pacific AI Association (AAIA). Sumei's current research interests include next-generation communications, sensing-communications-computing-control integrative design, applied AI, and next-generation transportation systems. She's recipient of the IEEE ComSoc Donald W. McLellan Meritorious Service Award 2024, IEEE ComSoc Inaugural Asia Pacific Women in Communications Engineering Outstanding Achievement Award (2024), 2023 IEEE VTS Women's Distinguished Career Award, and Singapore National Day 2022 Public Administration Medal (Bronze).

Presentation synopsis

Pervasive Connectivity for Real-Time and Embodied Intelligence: Powering the Next Frontier of Maritime Transformation

Digitalisation, decarbonisation, intelligence, automation, and autonomy are driving the transformation of maritime transportation. Achieving these goals requires high-fidelity, real-time situational awareness to enhance navigational safety, operational efficiency, and emission-aware decision-making in complex maritime environments. Integrated 5G and emerging 6G terrestrial and non-terrestrial networks (TN-NTN), combined with native AI and sensing, are poised to enable real-time connected and embodied intelligence for reliable maritime operations in congested ports, coastal waters, and beyond-line-of-sight environments.

This keynote will highlight how maritime AI is advancing next-generation vessel traffic management and improving operational efficiency while supporting decarbonisation. It will underscore the importance of high-fidelity spatial-temporal data streams for high-performance AI models and outline a roadmap for integrated 6G TN-NTN communications, sensing, and AI as key enablers of connected maritime intelligence. The talk will conclude with emerging opportunities and research directions for resilient, intelligent, and sustainable maritime ecosystems.

PANEL MEMBERS OVERVIEW

MODERATOR

Associate Professor Tay Chuan Beng
Acting Cluster Director
Programme Lead for the Future Ship and System Design R&D Programme
Singapore Institute of Technology



Assoc Prof Tay Chuan Beng is the Programme Lead for the Future Ship and System Design R&D Programme. He is currently a faculty member at Singapore Institute of Technology.

Assoc Prof Tay has been actively involved in the electrification of harbour crafts, contributing as a member of the Enterprise Singapore (ESG) Industry Task Force on the electrification of harbour crafts and the Standard Working Group on Electric Harbour Crafts Charging System.

PANELLISTS

Dr Liza Chua
Senior Engineer
American Bureau of Shipping (ABS)



Dr Liza Chua is a Senior Engineer at the American Bureau of Shipping (ABS) with expertise in maritime autonomous functions, virtual testing and the evolving regulatory landscape for maritime autonomy. Her work centres on advancing the safe and practical adoption of emerging technologies across the marine and offshore sectors, with a strong focus on verifying autonomous functions through virtual testing methods.

She is also actively involved in industry efforts related to the IMO MASS Code, contributing to the alignment of regulation and technology to support the future of autonomous shipping.

Mr Murthy Pasumarthy
Vice President (Technology), and Head
Seatrium Technology and Innovation



Mr Murthy Pasumarthy is the Vice President (Technology) and Head of Seatrium Technology and Innovation, responsible for overseeing the development of new products and Global Design Centers for Seatrium. He plays an integral role in the design and development of a wide range of projects, including offshore renewables, nearshore infrastructure, marine vessels, offshore semi-submersibles, Drillships, and Floating Production Units.

In his 20 plus-year tenure with Seatrium, Mr Pasumarthy has successfully guided his team in product design, project support, marketing support, and third-party services. He brings extensive experience in concept design, basic design, detail engineering, project management, pre-FEED and FEED engineering activities.

Mr Pasumarthy holds a Master's degree in Naval Architecture from Chalmers University of Technology, Sweden, and a Bachelor's degree in Naval Architecture from Andhra University, India. He is member of the Society of Naval Architects & Marine Engineers Singapore (SNAMES), Singapore and serves as a Member Joint Working Group on Onshore Wind, Singapore. He is the Member of Engineering Advisory Committee, Ngee Ann Polytechnic, Singapore. He was previously a member of the Committee on Ammonia Bunkering at the Singapore Chemical Industry Council.

Mr Odd Erik Mørkrid
Research Manager
Energy and Transport
SINTEF Ocean AS



Odd Erik Mørkrid holds a master's degree in Engineering Cybernetics from NTNU in Trondheim/Norway in 2008, specialty within guidance, navigation and control. He has a long experience with simulator-based (HIL) testing and verification of control systems (DP, PMS, thruster control etc) in offshore and maritime industries.

In recent years he has worked with research and project management of large Horizon Europe projects within the field of autonomous shipping, port operations and logistics. Currently involved in two of the major autonomy projects in Europe, AUTOFLEX and SEAMLESS.

Odd Erik is now holding the position as research manager of the Maritime autonomy and robotics research group in SINTEF Ocean, with focus on both autonomous surface vessels and underwater vehicles.

Dr Nigel Koh
Senior Director
Technology Centre for Offshore and Marine, Singapore (TCOMS)



Dr Nigel Koh is the Senior Director (Maritime System) at the Technology Centre for Offshore and Marine, Singapore (TCOMS), a position he has held since October 2025.

Before joining TCOMS, Dr. Koh held senior positions at the Defence Science and Technology Agency (DSTA), Keppel Offshore & Marine Technology Centre, Keppel Singmarine, and Singapore Technologies Marine.

He holds a Doctor of Philosophy in Marine Technology from Newcastle University, a Master of Science in Maritime Studies from Nanyang Technological University, and a Bachelor of Engineering with First Class Honours in Small Craft Technology from Newcastle University. Dr. Koh is a Fellow of the Royal Institution of Naval Architects.

PARALLEL SESSION OVERVIEW

Parallel Session Topics:

Parallel Session No.	Title	Author
Parallel Session 1: Smart Ships (1.00pm – 3.00pm, 22 Apr 2026)	Addressing Challenges in Autonomous Shipping: Insights from a Singapore Pilot Project and the Emerging Role of Agentic AI	Bernad Peter Francis
	Simulation-Based Validation of Autonomous Navigation System in Singapore Waters	Tomoaki Yamada
	Application of Model-Based System Engineering to Maritime Autonomy	Liza Chua and Robert Ong
	Enabling Safe and Scalable Autonomous Shipping in Congested Maritime Environments	Aranya Mitra
	Formal descriptions of MASS Operational Envelope and Operational Design Domain	Ørnulf Jan Rødseth
	“How do I trust my computer vision system” The role of Assurance in supporting a thriving Maritime Autonomy sector	Andre Burgess
	Efficient Data Association and Hypothesis Management for Multiple Extended Object Tracking in Maritime Applications	Martin Baerveldt
	Maritime Autonomy and its Impact on European Shipping	Christoph Burmeister
Parallel Session 2: Maritime Energy (1.00pm – 3.00pm, 22 Apr 2026)	Opportunities and Challenges for Maritime Nuclear	Michael Bluck
	A Case Study of Full-Electric Pilot Launch – From Ship Design, Operations Optimisation, to Fleet Charging Demand Estimation	Tay Chuan Beng

Parallel Session No.	Title	Author
Parallel Session 2: Maritime Energy (1.00pm – 3.00pm, 22 Apr 2026)	Assessing the Environmental Impacts of Alternative Fuels: A Fugitive Emission Study	He Zhengxin
	Mitigation of Ammonia Leaks during Bunkering Operations using Water Curtains - A CFD Study	Lau Yang Hao
	Mitigation of Ammonia Loss of Containment (LOC) During Bunkering Using an Air Curtain	Anthony B. Hamzah
	Two-Phase Ammonia Flowmeter Performance Verification System	Ye Shaochun
Parallel Session 3: Smart Ships (3.20pm – 5.20pm, 22 Apr 2026)	Towards a Maritime RF Digital Twin for Predictive Connectivity and Autonomous Ship Operations in Singapore Waters	Hoang Anh Tuan
	Virtual Testing for MASS: A Comprehensive Review of Current Practices, Gaps, and Standardisation Needs	Ten Yao Hua
	Development of a Mathematical Manoeuvring Model toward Constructing a Safety Assessment Environment for MASS	Makoto Ito
	A Robust Simulation Framework for Verification and Validation of Autonomous Maritime Navigation	Mayur Shivaji Patil
	Situation Awareness Through Shared Control: Safety-Assisted Remote Maritime Operations	Andreas Gudahl Tufte
	Visual Rule-Guided Deep Reinforcement Learning for Autonomous Ship Navigation in IALA-Regulated Port Environments	Liu Yuqing
	A Web-Based Virtual Test Environment for Autonomous Navigation Systems Validation	Daniel Liu

Parallel Session No.	Title	Author
Parallel Session 4: Maritime Cybersecurity (3.20pm – 5.20pm, 22 Apr 2026)	Resilient Maritime Localisation Using 5G Non-Terrestrial Networks Against GNSS Spoofing and Jamming	Ma Yugang
	StormShield: A Semi-Markov-Driven Defense Against DDoS Attacks in NMEA 2000 Maritime IoT Systems	Kamel Abbad
	Navigating the Gaps: Understanding AIS Data Reliability — A Big Data Framework for Analysing Missing Patterns	Zhao Liangbin
	Simulator-Based Visualisation of Cyberattack Effects for Maritime Cybersecurity Training	Gayatri Kumar Tota
	Cyber Attacks Against Remote Operations Centres: Risks and Legal Implications	Fatih Durmaz
	Multilink Connectivity Framework for Seamless Switch-over	Goh Lee Kee
	Modeling and Engineering Cyber-Safety Causality in Autonomous Maritime Navigation	Sinem Getir Yaman
	On the Development of Scalable and Modular Ka-band SATCOM Terminal for Tropical Ocean	Qing Xianming
Parallel Session 5: Smart Ships (9.00am – 10.15am, 23 Apr 2026)	From CONOPS to approval: Regulatory and commercial pathways for demonstrating autonomous inland shipping between Terneuzen and Ghent	Odd Erik Mørkrid
	Agent-Based Multimodal Retrieval and Regulation Analysis for Automated Ship Design Compliance	Yi-Lun Huang
	Adaptive Design and Operations for Next-Generation Ships under Uncertainty via the MODE Simulation Platform	Takuya Nakashima

Parallel Session No.	Title	Author
Parallel Session 5: Smart Ships (9.00am – 10.15am, 23 Apr 2026)	Deep Reinforcement Learning Based Safety-critical Scenario Generation for Autonomous Ship Digital Testing	Wang Hongwei
	Turku University of Applied Sciences Testbed for Resilient Uncrewed Surface Vessels	Jarkko Paavola
Parallel Session 6: Cargo Optimisation (9.00am – 10.15am, 23 Apr 2026)	Preventing Collisions with Critical Port Infrastructure: An Incident-Driven Approach to Designing a Shore-Based Assistance System	Sebastian Feuerstack
	Working Together is Success: Human-Machine Teaming to Increase the Use of Calculated Shipping Routes to Reduce Emissions	Adam Sobey
	MARKS: An AI-Driven MARitime Risk Knowledge System (MARKS) for Disruption Event Profiling and Supply Chain Impact Projection	Wang Ke
	Dynamic navigation and Port call optimization in real time	Kay Endre Fjørtoft
	Integrating Agentic AI into Maritime Logistics: Towards Autonomous, Sustainable and Resilient Port Ecosystems	Chiara Saragani
Parallel Session 7: (8.00am – 12.30pm, 23 Apr 2026)	SMU Maritime Thought Leadership: Stakeholder Integration – towards a future maritime ecosystem empowered by AI	
Parallel Session 8: Smart Ships (10.30am – 11.45am, 23 Apr 2026)	Situation Awareness by Design: Consensus-Based Interface Design for Maritime Teleoperation	Alexey Gusev
	Considering the Intended Behaviour in Evaluating the Rule Compliance of MASS	Nina Wetzig
	Computer Vision Based Early Detection of Container Loss at Sea	Vishakha Lall

Parallel Session No.	Title	Author
Parallel Session 8: Smart Ships (10.30am – 11.45am, 23 Apr 2026)	Formal Specification of COLREG Steering and Sailing Rules	Bernd Westphal
	Study on Emergency Collision Avoidance for Autonomous Ships	Li Meng Xuan
Parallel Session 9: Cargo Optimisation (10.30am – 11.45am, 23 Apr 2026)	The Pulse of Maritime AI: Recent Developments, Sector Implications and Ongoing Research	Panagiotis Angeloudis
	Automated Cargo Allocation for Maritime Tankers: Hybrid Optimisation and ML for Efficiency and Safety	Tan Peng Hui
	AI-Enabled Metocean Intelligence for Safe and Efficient Maritime Operations	Ruoying He
	Programmable 5G Network for Enabling Smart Port Operation	Gary Lee
	Joint Arrival Scheduling and Fuel-efficient Control for Smart Ships with Multi-agent Reinforcement Learning	Yang Xun
Parallel Session 10: Smart Ships (2.00pm – 3.15pm, 23 Apr 2026)	Construction of HiLS Environment and Issues Organisation Corresponding Toward Certification Acquisition of Collision Avoidance System of Autonomous Ship	Keisuke Tanihara
	CFD-Based Analysis of Ventilation Design and Explosion Risk for Electric Harbourcraft Battery Room	Chong Mei Yan
	Spatiotemporal Patterns and Predictive Risk Analysis of Maritime Accidents in UK Waters	Jizhou Tang
	Understanding Aerodynamic Forces and Wake Flows Around Container Stackings Through Scaled Experiments and CFD Validation	Barathi Boppana

Parallel Session No.	Title	Author
Parallel Session 10: Smart Ships (2.00pm – 3.15pm, 23 Apr 2026)	Navigating in Waves and Currents: Challenges for Ship Maneuverability and Autonomy	Kudupudi Ravindra Babu
Parallel Session 11: Cargo Optimisation (2.00pm – 3.15pm, 23 Apr 2026)	Information Asymmetry in FCFS Port Queues: A Game Theoretic Analysis of “Sail Fast, Then Wait”	Ayato Kitadai
	Characterising Vessel-Cable Interaction and Seabed Events Using Distributed Acoustic Sensing (DAS) for Maritime Safety Applications	Vuong Nhu Khue
	Sizing for Operational Excellence: A Simulation-Driven Study of Barge Scale in Inter-Terminal Transport for Next- Generation Port Efficiency	Liu Mengya
	Towards Next Generation Port Service Intelligence: Leveraging Generative AI and Reinforcement Learning for Cruise Vessel Berthing Plan Optimisation	Yin Xiao Feng

PARALLEL SESSION 1: SMART SHIPS

Addressing Challenges in Autonomous Shipping: Insights from a Singapore Pilot Project and the Emerging Role of Agentic AI

Bernad Peter Francis¹, Pasumarthy Murthy¹, Merchant Aziz¹, Chen Zhuo²

¹Seatrium Technology and Innovation, Singapore

²National University of Singapore, Singapore

Abstract:

An autonomous vessel developed by Seatirum has successfully completed sea trials in Singapore. Both remotely controlled and autonomous navigation trials were carried out in the Port of Singapore in 2022, marking a significant milestone. This milestone includes being the first remote control vessel trial in South East Asia to feature joystick steering and lever control, as well as being the world's first to receive the ABS' prestigious AUTONOMOUS and REMOTE-CON Notation.

To simulate the challenging traffic conditions in one of busiest ports in the world, the vessel engaged in autonomous collision avoidance trials amidst dynamic obstacles with varying speeds and courses. These trials showcased the vessel's exceptional collision avoidance capabilities under diverse scenarios such as head on, crossing and overtaking, crucial for safe operations in the busy port waters.

Moreover, a comprehensive concept of operations (ConOps) for remote control and autonomous navigation in port water has been developed through this project. This ConOps delves into the operational envelope, function integration, command transfer, ship-shore communication methodology, and more, setting a solid framework for future operations.

In addition to these achievements, this pilot project underwent a rigorous 6-month data collection phase. A vast amount of data, including images and videos captured under normal operating conditions, was amassed during this phase. Leveraging this data, an AI model for marine object detection was crafted, exhibiting an impressive accuracy against test data and field-testing data.

This paper encapsulates pivotal discoveries and challenges encountered during this transformative journey, offering valuable recommendations to shape the future of remotely controlled and autonomous operations.

Simulation-Based Validation of Autonomous Navigation System in Singapore Waters

Yamada Tomoaki¹, Ito Makoto¹, Majima Takahiro¹, Nakamura Shinya², Sawada Ryohei², Minami Makiko³, Sato Keiji³, Nomoto Hideki⁴, Hirose Takayuki⁴, Michiura Yasutaka⁴

¹ClassNK, Japan

²Japan Captains' Association, Japan

³National Maritime Research Institute, Japan

⁴Japan Manned Space Systems Corporation, Japan

Abstract:

The development of Maritime Autonomous Surface Ships (MASS) has been accelerating globally, driven by the need to enhance safety, efficiency, and sustainability in maritime transport. To support this transition, the International Maritime Organisation (IMO) is drafting the MASS Code as an international regulatory framework for autonomous ships. The non-mandatory version of the MASS Code is expected to be adopted at the 111th session of the Maritime Safety Committee (MSC 111) in May 2026. Following its adoption, the industry will enter the Experience-Building Phase (EBP), during which technology validation and operational concept evaluation using actual vessels will play a critical role.

However, as highlighted in ClassNK's Guidelines for Automated/Autonomous Operation on Ships (Ver. 2.0), thorough verification of Autonomous Navigation System (ANS) through simulation is essential prior to onboard implementation. Simulation-based validation enables performance assessment under complex and high-risk scenarios without compromising safety. This approach is particularly important in highly congested and operationally challenging waters.

In this study, we focus on the Singapore Strait, one of the world's most congested waterways, and develop scenarios that replicate realistic traffic patterns, navigational risks, and operational constraints. The ANS developed by some of the authors will be tested using a full-mission Ship Handling Simulator (SHS). To ensure practical relevance, expert judgment will be provided by experienced captains with extensive knowledge of navigation in the target area.

The primary objectives of this research are to (i) establish a robust methodology for evaluating ANS performance in congested waters, (ii) identify potential limitations and failure modes under realistic conditions, and (iii) provide insights that contribute to improving system reliability and safety. By integrating simulation-based testing with expert evaluation, this initiative aims to support the development of standardised validation protocols during the EBP, facilitate regulatory compliance, and promote industry best

practices. Ultimately, the findings are expected to accelerate the safe and effective deployment of autonomous navigation technologies and contribute to the global adoption of MASS.

Application of Model-Based System Engineering to Maritime Autonomy

Chua Liza¹, Ong Robert², Ten Yao Hua¹, Geng Qin¹,

¹American Bureau of Shipping, Singapore

²International Council on Systems Engineering, Expert Systems Engineering Professional

Abstract:

This presentation showcases an ongoing initiative on the application of Model-Based Systems Engineering (MBSE) to maritime systems, demonstrating how MBSE approach can strengthen system design, integration, and verification for increasingly complex vessels. As an initial use case, the work explores the translation of existing ABS classification requirements into structured digital rule models and developing supporting domain ontologies. These efforts established a foundation for an architecture framework that can be practically applied in maritime systems lifecycle.

Rather than treating classification rules/requirements as static documents, the rules/requirements are modelled in SysML v2 as “digital rules” that can be linked to system functions, interfaces, and performance parameters. This enables end-to-end traceability from regulations to architecture, simulations, and verification activities, and allowing rule compliance assessable directly within the engineering models.

The presentation will outline the workflow developed with industry partners: selecting target rule sets, translating them into structured requirement models, linking them to system and subsystem models (e.g., propulsion, control, autonomy), and using these models to drive test cases, simulation scenarios, and acceptance criteria. Practical examples will illustrate how this approach improves change management as requirements or design concepts evolve, and how it supports consistent interpretation and application of requirements across various stakeholders.

Key observations such as the benefits and challenges will be highlighted. The session concludes with future steps towards enabling these digital rule models to be directly applied in both system design and certification / approval activities, supporting a more consistent and traceable digital pathway for demonstrating compliance throughout a vessel’s lifecycle.

Enabling Safe and Scalable Autonomous Shipping in Congested Maritime Environments

Mitra Aranya¹

¹MarineAI Ltd Plymouth, UK

Abstract:

The global maritime industry is entering a critical transition phase, where autonomous shipping technologies are moving from controlled trials toward routine operations in live, congested waterways. While advances in hardware and artificial intelligence have accelerated technical readiness, real-world deployment continues to expose challenges around perception reliability, collision avoidance, remote control assurance, and regulatory compliance. This presentation draws on operational experience from autonomous vessel trials in UK and international waters to examine how a modern autonomy stack is being engineered to safely integrate with existing maritime traffic and practices.

Sensor fusion and perception systems form the foundation of autonomous navigation. In complex maritime environments, no single sensor provides sufficient reliability across all conditions. This talk explores how multi-modal sensor fusion—combining radar, AIS, GNSS, inertial navigation, computer vision, acoustics, and LiDAR—can be used to generate a unified, confidence-weighted situational awareness model. Emphasis is placed on sensor health monitoring, hierarchical sensor ranking, and failover strategies that maintain navigational integrity during partial sensor degradation, particularly in coastal and harbour environments where clutter and interference are common.

Building on perception, **collision avoidance algorithms** must interpret intent, predict vessel behaviour, and execute compliant manoeuvres. The presentation examines the application of a COLREG-aware tactical planner that combines predictive contact tracking with rule-based and adaptive decision logic. Lessons learned from live autonomous operations demonstrate how collision avoidance systems must balance determinism with flexibility, especially when interacting with crewed vessels exhibiting ambiguous or non-standard behaviour. The role of human-in-the-loop and decision-supported autonomy modes is discussed as a pragmatic pathway toward higher autonomy levels.

The talk then addresses **remote vessel control systems** as a critical enabler of safe autonomy adoption. Beyond basic teleoperation, modern remote operating centres (ROCs) provide supervisory control, intervention capability, and regulatory assurance. Topics include secure command-and-control architectures, low-bandwidth resilience,

safety-case-driven fail-safe states, and the integration of autonomy engines that can degrade gracefully from autonomous to remotely controlled operation when required.

Finally, the presentation focuses on **autonomous navigation in congested waters**, where the interaction between technology, human mariners, and existing maritime infrastructure is most acute. Case studies from harbour trials, defence exercises, and over-the-horizon operations illustrate how autonomy systems can be validated incrementally through crawl-walk-run deployment models, simulation-to-sea pipelines, and close collaboration with regulators and port authorities.

Together, these insights highlight that the successful adoption of autonomous shipping is not solely a technical challenge, but a systems integration and operational assurance problem—one that demands robust perception, transparent decision-making, and trusted human-machine collaboration.

Formal descriptions of MASS Operational Envelope and Operational Design Domain

Rødseth Ørnulf Jan¹, Wenersberg Lars Andreas Lien²

¹Norwegian Forum for Autonomous Ships, Norway

²SINTEF Ocean, Norway

Abstract:

The International Organisation for Standardisation (ISO) published a definition of the Maritime Autonomous Surface Ship's (MASS) Operational Envelope (OE) in its technical specification ISO/TS 23860 in 2022. This definition has later been somewhat modified by the International Maritime Organisation (IMO) in its work on a voluntary code for MASS. IMO also introduced the use of the MASS Operational Design Domain (ODD), based on a similar definition in SAE J3016 which was developed for a car's driving automation system. With the advent of the IMO voluntary code for MASS that is based on the definition of certain high-level goals, we see a need for better tools to describe the exact capabilities of the automation system. This does in particular apply in the context of responsibility sharing between crew in the Remote Operations Centre (ROC) and the onboard automation systems. An outline of the principles for such a description framework has been presented in previous papers and is also included in the informative annexes in the ISO/TS 23860. To progress, there is a need to develop these description formats further and make them fully aligned with definitions and requirements in the MASS code. This work has been proposed as a new standardisation work item to ISO and was approved by ISO in November 2025. The proposed standard, ISO 25922, will emphasise the clear definition of responsibilities between the automation systems and the remote crew for the different autonomous functions onboard a ship, and it will contain a framework to build the trust the operator must have in the autonomous capabilities of the automation systems. This also includes exception handling and fallback situations. An essential element in these descriptions is how to allow enough time for the operator to gain situational awareness when the operator needs to take over control from the automation. In most cases we are looking at constrained autonomy where automation systems have full control of the ship under defined and restricted conditions, and where remote crew take over control when necessary. To ensure a tolerable risk level for MASS, many technical and operational measures are needed, but relevant to the collaboration between crew in the ROC and automation on the ship, the following are central: 1) The automation system's operational limitations; 2) What party is in control at any point in time, ROC crew or automation; 3) Avoidance of out-of-the-loop problem when crew needs to take over control from automation; and 4) The actual hand-over process.

“How do I trust my computer vision system” The role of Assurance in supporting a thriving Maritime Autonomy sector

Burgess Andre¹

¹National Physical Lab, UK

Abstract:

While Maritime Autonomy promises great benefits, a paradigm shift in how uncrewed and autonomous technologies are tested, certified and assured through their operational lifecycle is required. There are many reasons for this, not least that New measures of confidence are required for technologies where critical decisions are not being made by humans, and where safety must be maintained through operations.

The perception system is a critical component for safe and effective navigation. Confidence is key here and if we are unable to assure Maritime Autonomous technologies, exploitation and benefits risk being significantly inhibited, slowing/limiting innovation & ecosystem growth potential.

In response to these challenges and needs; the UK-led Maritime Autonomy Assurance Testbed (MAAT) programme has been set up to deliver an internationally relevant assurance capability for Maritime Autonomy, supported by pro-innovation standards, and not constrained by existing human-centric approaches.

This talk will show how MAAT is using cutting edge science to deliver innovative testbeds to test and evaluate sensors and data fusion technologies, as well as whole systems, to enable industry development and exploitation.

The MAAT programme is based out of Plymouth, which has been designated the National Centre for Marine Autonomy. NPL has, as part of the MAAT programme, established its first sensor test node on the sound. This is in collaboration with the Met Office, Plymouth Marine Lab, The University of Plymouth, and its cutting edge nature forms the foundations for imminent expansion over Plymouth Sound. This new test range will support the UK's maritime autonomy ambitions by:

- Providing traceable quantification of sensors performance in UK coastal conditions and understanding how this will affect the ability to detect objects and make correct navigational decisions, supporting the validation of the perception systems algorithms.
- Utilising ground truth data to improve the accuracy of simulation models critical for verifying and validating complex autonomous systems.

- Generating a real time digital twin of Plymouth Sound, expanding testing environments for uncrewed systems and improving the quality of trial outputs.

Through the construction of an environment that has extensive sensor deployment alongside weather data capture, we are able to map in real-time, all objects that are present. This is accompanied by well characterised uncertainty and provides a traceability chain of confidence for tests undertaken.

The MAAT programme is now establishing collaboration with partners in Singapore to develop this as an international capability.

Working within the Security and Resilience Group at NPL, Andre Burgess has led the creation of its Assured Autonomy Programme, which brings together disciplines across Data Science, Time and Frequency, Electro-Magnetic technologies and Dimensional metrology. His work on Autonomous Transport Systems has focused on delivering confidence in the adoption of these emerging technologies. This includes building collaborations across the UK's mobility sector (Land, Sea and Air) to establish an integrated digital measurement infrastructure and technical framework to underpin the testing ecosystems – real and virtual - for autonomous systems at all Technology Readiness Levels. Over the last 4 years Andre has coordinated NPL's involvement in the Maritime Autonomy Assurance Testbed programme. This is a UK initiative which follows a data-driven and evidence based approach to deliver an internationally relevant assurance capability supported by pro-innovation standards, and not constrained by existing human centric regulatory frameworks. This will deliver a framework to Test, certify and operationally assure maritime autonomous technologies globally, from component through to System of Systems. Andre has over 25 years' experience in the TMT sector having worked across Tier 1 Telecoms operators as well as setting up an international digital products and services company and supporting the launch of several start ups.

Efficient Data Association and Hypothesis Management for Multiple Extended Object Tracking in Maritime Applications

Baerveldt Martin¹, Brekke Edmund¹

¹NTNU, Department of Engineering Cybernetics

Abstract:

Situational awareness is critical for autonomous maritime systems, which require continuous understanding of the surrounding environment for safe operation. Reliable awareness of nearby vessels, including their position, motion, and spatial extent, is essential for navigation and collision avoidance. Multi-object tracking (MOT) methods are typically used for this task, since it is unknown which vessel generated each measurement. In confined waterways, the challenge is amplified as vessels operate in close proximity, requiring accurate estimation of their spatial extent. This motivates the use of multiple extended object tracking (MEOT) methods, which estimate both the kinematic state and spatial extent of multiple targets based on all available measurements.

However, MEOT methods are computationally demanding due to the complexity of extent modeling and the combinatorial nature of measurement association. This is particularly true for the Poisson multi-Bernoulli mixture (PMBM) filter, which maintains multiple association hypotheses and evaluates their likelihoods. Two main strategies are commonly used for data association in MEOT: the cluster-and-assignment (C&A) method¹, which generates multiple measurement partitions by varying clustering parameters, and the stochastic optimisation (SO) method², which samples measurement associations according to the underlying likelihood function. While C&A explores alternative partitions deterministically, it becomes expensive as the number of hypotheses grows, whereas SO achieves higher accuracy at the cost of extensive sampling. These challenges are further amplified for Gaussian Process (GP)-based extent models, which provide high accuracy but increase computational cost.

In this paper, we propose an efficient variant of the GP-PMBM filter³ that reduces computational complexity through improvements in both data association and hypothesis management. The data association stage combines the strengths of C&A and SO through a two-step strategy: spatial clustering to limit the number of plausible associations, followed by a Gibbs sampling step that assigns clusters to existing or new objects using the underlying likelihood model. In addition, we apply hypothesis management techniques, including pruning and merging functionally similar hypotheses, to reduce the number of global hypotheses maintained by the filter. Together, these strategies address the main computational bottlenecks of PMBM-based MEOT.

We will evaluate the proposed method on the recently released Maritime Urban Tracking (MUT) dataset⁴. Performance will be assessed using the Generalized Optimal Sub-Pattern.

References:

1. K. Granstrom, C. Lundquist, and O. Orguner, "Extended Target Tracking using a Gaussian-Mixture PHD Filter," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 48, no. 4, pp. 3268–3286, Oct. 2012, doi: 10.1109/TAES.2012.6324703.
 2. K. Granström, L. Svensson, S. Reuter, Y. Xia, and M. Fatemi, "Likelihood-Based Data Association for Extended Object Tracking Using Sampling Methods," *IEEE Transactions on Intelligent Vehicles*, vol. 3, no. 1, pp. 30–45, Mar. 2018, doi: 10.1109/TIV.2017.2788184.
 1. [3] M. Baerveldt, M. E. Lopez, and E. F. Brekke, "A Multiple Extended Object Tracker with the Gaussian Process Model Utilizing Negative Information," *Journal of Advances in Information Fusion*, vol. 19, no. 2, pp. 88–108, Dec. 2024.
 2. [4] N. Dalhaug, "MUT: Maritime Urban Tracking Dataset." NIRD RDA, 2025. doi: 10.11582/2025.L0RCNF5K.
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Maritime Autonomy and its Impact on European Shipping

Burmeister Hans-Christoph¹, Koch Paul¹, Constapel Manfred¹

¹Fraunhofer CML, Germany

Abstract:

Maritime Autonomous Surface Ships (MASS) need to carry out collision-avoidance manoeuvres in accordance with the International Regulations for Preventing Collisions at Sea (COLREGs). This requires not only correct assessment of the COLREGs encounter situations and obligations, but also monitoring of the collision avoidance manoeuvres carried out - by the MASS but also by the surrounding vessels. Based on our previous work¹ that introduced a rule-based system to assess COLREGs situations, this paper outlines a concept to assess whether vessels apply COLREGs-compliant manoeuvres or not. Each situation is represented as a set of annotations, where each set comprises different pieces of information about the situation. Transition between situation patterns occur due to manoeuvres or after passings. Situation patterns for overtaking, head-on, and crossing encounters situation patterns are linked and predictable for expected outcomes. By observing situations and their transitions, the system can classify manoeuvres as compliant, insufficient, or incorrect. The method preserves the transparency and traceability of symbolic rule-based reasoning while extending it into the temporal domain, enabling automated behavioural assessment suitable for MASS navigation systems, simulation studies, and large-scale AIS-based validation. To evaluate the approach, we employ a low-fidelity simulation tool that generates trajectories from a compact descriptive language. These trajectories allow controlled creation of compliant and non-compliant encounter scenarios, which are then fed into the assessment module to produce the corresponding sequences of annotation sets. This simulation-driven validation demonstrates how the developed framework can be applied to correct and incorrect manoeuvre patterns, providing an environment in which to systematically test the sensitivity and robustness of the presented assessment method.

Reference:

1. M. Constapel et al, On the implementation of a rule-based system to perform assessment of COLREGs onboard maritime autonomous surface ships, J. Phys.: Conf. Ser. 2311 012033, 2022.

PARALLEL SESSION 2: MARITIME ENERGY

Opportunities and Challenges for Maritime Nuclear

Bluck Michael¹

¹Imperial College London, UK

Abstract:

Nuclear propulsion has a long history in the defence sector, providing extended at-sea operation in support of strategic military deployment. Driven by concerns over energy security and net-zero ambitions, the commercial maritime transport sector is looking to move away from conventional fossil fuel propulsion and nuclear is potentially a strong option. Recent developments in the form of small-modular reactors are potentially well aligned with this, yet we are some way from the selection of appropriate technologies, establishment of regulatory frameworks and the necessary international agreements in a global industrial sector. In this presentation, we will look at these opportunities and challenges for commercial maritime nuclear.

A Case Study of Full-Electric Pilot Launch – From Ship Design, Operations Optimisation, to Fleet Charging Demand Estimation

Tay Chuan Beng¹, Chia De Wang¹, Wang Xin¹, Zheng Jianxin¹, Feng Xue Elsa¹, Boggarapu Yasho Bharat¹, Roslan Sharul Baggio¹, Chong Chin Soon¹, Ying Chen Hao¹, Low Malcolm¹

¹Singapore Institute of Technology, Singapore

Abstract:

This paper presents a simulation-based case study of a fleet of full-electric pilot launch boats, encompassing ship and system design optimisation, potential operational model optimisation, and shore charging demand estimation.

Ship design optimisation is an iterative process, usually with conflicting objective functions. In this study, an integrated approach for ship-system simulation, system sizing, and vessel design has been developed to optimise the vessel's energy efficiency and endurance. In the vessel optimisation process, realistic vessel operation profiles and task requirements, based on AIS data, were used to account for various operational scenarios of pilot launches.

In parallel, an optimisation of the operational model was conducted to explore alternative deployment and scheduling strategies that enhance fleet utilisation and service availability. By integrating simulated vessel performance with historical operational data, various fleet deployment models were evaluated. The operational model was optimised through multi-objective analysis, balancing energy consumption, turnaround time, and service coverage.

A statistical approach was proposed to estimate charging demand for a full-electric pilot launch fleet using historical operational data. The historical behaviour of the launch boats is first analysed, and the behaviours of the e-launch boats are estimated using a rule-based method that considers detailed technical and operational requirements. These estimations are then aggregated to determine the charging demands at a fleet level using a Monte-Carlo simulation approach. A case study based on practical scenarios will be presented to demonstrate the significance of the proposed approach and how it can be used to guide shore infrastructure design.

Assessing the Environmental Impacts of Alternative Fuels: A Fugitive Emission Study

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²School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

*Corresponding Author: Tan Shu Fen, Liu Ming

Abstract:

As maritime decarbonisation advances, alternative fuels such as methanol, ammonia, and hydrogen are being increasingly adopted. Existing studies have primarily focused on direct greenhouse gases from combustion, while overlooking fugitive emissions arising from fuel slip. These fuels are toxic in nature; a smaller amount will lead to significant environmental concerns. The importance of handling the vapour loss has been widely reported by maritime safety guidelines published by classification societies. Regulators have likewise recognised this gap; for example, the International Maritime Organization has explicitly included fugitive emissions for further development in the Life Cycle Greenhouse Gas Assessment Framework at the 83rd session of the Marine Environment Protection Committee.

To address this gap, this paper systematically compares the environmental impacts of fugitive emissions from three alternative fuels: methanol, ammonia, and hydrogen on an equal energy basis, expressed per kilowatt-hour of engine output. We study the physical dispersion and atmospheric chemistry using numerical modelling to understand the formation of potential chemical species resulting from fugitive emissions into the atmosphere. Based on these results, we construct a time-resolved emission inventory and quantify the consequential environmental impacts, such as climate change, ozone formation, and toxicity for human health. Our preliminary results indicate that meteorological factors, such as wind speed and temperature, are important in determining the amount and dispersion of fugitive emissions across all fuels in this study. For methanol, aldehyde-dominated chains are the primary drivers of ozone-related burdens. On the other hand, nitrous oxide formed from fugitive ammonia and hydrogen emissions is the primary contributor to the near-term climate impact. An in-depth understanding of the dispersion, dilution, and degradation of fugitive emissions can provide critical considerations for alternative fuels adoption pathways.

Mitigation of Ammonia Leaks during Bunkering Operations using Water Curtains - A CFD Study

Lau Yang Hao¹, Venugopalan Raghavan¹, Boppana Bharathi¹, Chan Ronald¹ Leong Jason¹, Nguyen Vinh-Tan¹

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Abstract:

Among alternative marine fuel candidates, ammonia is a promising carbon-free fuel for meeting the IMO 2050 target to halve shipping greenhouse gas emissions. Recent trials of ammonia transfer and bunkering in Singapore and elsewhere pave the way for the imminent adoption of ammonia to decarbonise the maritime and energy sectors. However, the high volatility, toxicity, and corrosiveness of ammonia present significant safety challenges. Accidental leaks due to various incidents, including hose disconnection and pipe ruptures, will result in the spread of hazardous ammonia vapour clouds in the air and plumes in the water. This may cause irreversible damage to nearby ships, infrastructure, human lives, and the environment. Effective mitigation strategies for ammonia leaks are therefore critical to ensure safe use of ammonia in maritime applications.

Among leak mitigation strategies, one of the most commonly considered approaches in industry is the use of water curtains, due to their low cost and widespread availability, as well as the high solubility of ammonia in water. Additionally, water curtains have been postulated in several studies to effectively reduce ammonia concentrations and limit the range of ammonia plumes. However, the effective deployment of water curtains to contain ammonia leaks during ship operations remains unclear. Field-testing curtains in realistic leak scenarios is expensive and dangerous. As such, we model the impact of water curtains on ammonia leaks during bunkering using CFD simulations, which can handle complex geometries and multi-directional flows.

We selected one of the most credible scenarios in ammonia bunkering operations to study in this work. The simulated conditions include vessel designs, ammonia storage pressure and temperature, leak rates and durations, and environmental factors such as wind speed, temperature, humidity, and atmospheric stability. To model effects of water, the multiphase flow simulations incorporate ammonia-air-water interactions, including ammonia entrainment and absorption by water, as well as droplet dynamics. Water curtains are dispensed by high-pressure sprays with adjustable nozzle configurations and flow rates, for rapid response in confined or inaccessible areas. Because the mitigation efficiency of water curtains has been suggested to vary with droplet size, density, discharge rate, and proximity to the leak source, we investigate the impact of these

parameters in our simulations to identify discharge conditions that maximise ammonia absorption and dispersion.

We have validated our simulations against ammonia absorption curves from mean-field model predictions and indoor experiments. From simulations of leakage during bunkering, preliminary results show the ammonia plume is suppressed in the vicinity of water curtains. We expect to enlarge the plume-free area to cover critical regions around the leak by tuning water discharge parameters.

Our work contributes to deepening the fundamental understanding of water curtain effectiveness. We believe that this study will provide useful input for the formulation of emergency response protocols for future operations on how best to deploy water curtains. It is a step forward in an ongoing effort to develop proactive safety measures for and increase confidence in adopting ammonia-fuelled vessels, supporting the industry's transition toward sustainable shipping while safeguarding human health and the environment.

Mitigation of Ammonia Loss of Containment (LOC) During Bunkering Using an Air Curtain

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Abstract:

Bunkering remains the ‘critical link’ in the ammonia marine fuel value chain due to the risk of loss of containment (LOC). Even small ammonia releases can pose serious hazards to onboard personnel and surrounding areas, given ammonia’s low lethal toxicity threshold. Ensuring safe bunkering therefore relies heavily on safe infrastructure design and mitigation systems.

Water curtains have been proposed as a countermeasure against ammonia cloud release in maritime settings. However, their use generates large volumes of caustic runoff that can accelerate corrosion of decks and metallic structures if improperly untreated (e.g., insufficient post-mitigation flushing). Moreover, the large amount of alkaline runoff may require substantial quantities of additional water for dilution to reduce the ammonium concentration below safe aqueous thresholds, ensuring that its eventual discharge does not harm marine life. This study introduces an alternative approach: an air-based system for mitigating ammonia cloud dispersion following an LOC event: an air-based system using air as a barrier to block the path of the ammonia cloud while simultaneously diluting its concentration below the hazardous threshold.

The representative case involves a flange leak in a bunkering pipeline on a bulk carrier, which is the bunker receiving vessel. The ammonia fuel state in the containment is in subcooled-refrigerated state. The air curtain is installed along the bunker station perimeter to immediately prevent the spread of the two-phase ammonia cloud toward accommodation and other sensitive areas. It consists of multiple compressed-air nozzles ejecting fresh air at controlled velocities, forming a dynamic shear layer that deflects the ‘heavy’ ammonia cloud and promotes vaporization of aerosols into lighter-than-air ammonia vapor. This process directs the light vapor upward and away from personnel, reducing exposure risk.

Computational fluid dynamics (CFD) simulations were conducted to evaluate the system’s performance and its operating window in terms of minimum air barrier axial velocity. Ammonia concentrations at selected deck locations were tracked and compared to the AEGL-2 safety threshold of 220 ppm. A benchmark case using a conventional “peacock tail” type water curtain was also simulated for comparison.

Results show that an air curtain operating at moderate air velocity can effectively limit the ammonia cloud footprint, performing on par with or better than a water curtain, while avoiding excessive flushing associated with caustic runoff handling. The findings demonstrate the potential of air-based mitigation systems as viable alternatives for enhancing safety during ammonia bunkering and provide a basis for their integration into ship design and emergency response planning.

Two-Phase Ammonia Flowmeter Performance Verification System

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Abstract:

Ammonia is emerging as a key fuel for maritime decarbonisation. Mass Flow Meters are critical for the accurate fuel quantity measurement essential to reliable ammonia custody transfer, engine performance assessment, and regulatory compliance. However, their deployment is hindered by metrological challenges arising from the thermodynamic properties of ammonia, leading to pervasive presence of two-phase flow conditions. Addressing this gap, A*STAR National Metrology Centre has developed a high-fidelity two-phase ammonia flow system to verify flow meter performance. Employing a thermodynamic methodology rather than mechanical mixing, the facility generates a wide range of Gas Volume Fractions with measurement traceability anchored in the single-phase domain. This infrastructure moves the industry from theoretical derating to empirical validation, enabling the robust instrumentation required for the safety, efficiency, and regulatory compliance of next-generation ships powered by ammonia.

PARALLEL SESSION 3: SMART SHIPS

Towards a Maritime RF Digital Twin for Predictive Connectivity and Autonomous Ship Operations in Singapore Waters

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Abstract:

Reliable and robust connectivity is a key enabler for smart ships, autonomous navigation, remote pilotage, and data-centric maritime operations. However, ensuring reliable and robust communications in coastal and port waters is challenging due to sea-surface reflections, vessel-induced multipath, port infrastructure, and dynamic traffic conditions. These effects are particularly complex in Singapore's dense maritime environment. This paper presents our ongoing research toward developing a Maritime Radio Frequency Digital Twin (RF-DT) that models and predicts wireless performance across coastal and port waters, with the aim of forming a key component of MPA's Maritime Digital Twin (MDT).

Critical maritime functions such as real-time situational awareness and high-definition video streaming for remote pilotage depend on robust, low-latency wireless links. To guarantee such wireless links, there is a need for accurate channel prediction, e.g., for deployed maritime 5G or satellite links. However, existing channel models often fail to represent the unique propagation characteristics of Singapore waters, where semi-enclosed sea states, port infrastructure, and dense vessel movements create a highly dynamic RF environment. This highlights the importance of locally adapted maritime channel modelling.

We therefore propose a hybrid modelling approach that integrates: (i) Large-scale path-loss models, (ii) Small-scale fading distributions tuned to sea state and vessel class, (iii) Deterministic scattering from sea surface roughness, vessels, and infrastructure, and (iv) AIS-driven situational awareness, which captures the dynamic distribution and movement of ships that act as reflective or shadowing objects. This forms our data-driven RF-DT capable of both physics-based and operationally realistic predictions.

We also present preliminary field measurements in which we conducted 5G propagation measurements on a selected coastal route with our 5G modem from a commercial 5G SA basestation site located on St John Island. We measured the RSRP signal with our 5G UE mounted on roof-top of the boat for 3.5 GHz. Collected measurements show: (i) near-shore blockage due to hilly island terrain, (ii) free-space-like behaviour in the mid-

range due to directional antennas and MIMO beam steering at base station, and (iii) two-ray-like ripples beyond 2 km where LOS and sea-surface reflections interact. These findings also highlight the need for calibration using both controlled experiments and live sea-trials.

Our long-term goal is to integrate the RF-DT into the Singapore's broader Maritime Digital Twin. By fusing RF predictions with environmental data, vessel traffic, and operational contexts, the RF-DT can provide insights such as predicted outage zones, handover windows, and recommended routing for autonomous or remotely navigated vessels. Ultimately, a validated RF-DT will support resilient connectivity for smart ships, enhance operational safety, and enable robust connected maritime operations.

Virtual Testing for MASS: A Comprehensive Review of Current Practices, Gaps, and Standardisation Needs

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Abstract:

This paper presents a comprehensive literature review and landscape analysis of virtual testing for autonomous ship navigation and collision detection/collision avoidance (CDCA), with the objective of consolidating fragmented research and industrial practice into a structured overview that can inform future standards and certification frameworks for Maritime Autonomous Surface Ships (MASS). The review encompasses academic studies, regulatory and class-society publications, national and regional testbed activities, industrial developments and prototype testing initiatives, as well as early operational insights obtained from MASS simulators and sea trials.

Methodologically, the study employs structured searches across scientific databases, regulatory documents, industrial white papers, trial reports, and vendor materials to map the current state of the art in testing of autonomous CDCA systems. The analysis covers the types of scenarios (baseline, region-specific, edge and near-miss), test procedures, performance metrics, pass/fail criteria, coverage requirements, existing IMO maneuver tests applicability and the practical approaches and validation strategies adopted by developers. The review highlights strong growth in scenario-based testing, digital twins, high-fidelity simulators, and human-in-the-loop arrangements, with increasing focus on safety and reliability indicators tailored to autonomous functions. At the same time, the review identifies critical gaps, including the limited standardisation of safety metrics and acceptance criteria, inconsistent handling of critical/near miss or other edge scenarios derived from real traffic data, and challenges in the translation of virtual testing evidence into regulatory or class approval pathways.

Drawing from these observations, the paper outlines a high-level concept of an autonomous CDCA virtual testing framework. The paper highlights overarching elements

of the framework including consistent scenario development, clear evaluation metrics, harmonised safety and reliability indicators, and mechanisms for linking virtual testing outcomes to broader assurance pathways such as actual MASS trials, regulatory and class approvals, and crew training. The findings establish an important knowledge foundation and identify key areas from a maritime assurance perspective, motivating future efforts towards practical, standardised approaches to virtual testing of autonomous maritime systems.

Development of a Mathematical Manoeuvring Model toward Constructing a Safety Assessment Environment for MASS

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Abstract:

Ensuring the safety of Maritime Autonomous Surface Ships (MASS) is an essential step toward their social implementation. It is particularly important to verify scenarios that cannot be tested on actual ships through prior simulation, because real-world trials often involve high costs, operational constraints, and potential safety risks that make comprehensive testing impractical. To address this challenge, this study proposes the development of a simplified mathematical model toward constructing a safety assessment environment for MASS.

The aim of this study is to develop a simplified mathematical model for low-speed manoeuvring motion. Low-speed manoeuvring is particularly critical because operations in ports and confined waters demand precise control, which requires that the models used for verification accurately represent the complex dynamics involved. In this study, the manoeuvring model is constructed based on the concept of MMG (Manoeuvring Modelling Group) model, which adopts a modular structure to separately represent the forces acting on the hull, propeller, and rudder. In low-speed manoeuvring, hull hydrodynamic forces are highly non-linear and complex, requiring detailed modelling, while propeller and rudder operations during low-speed manoeuvres demand that the model be extended to cover all four quadrants of operation. To achieve simplification without sacrificing physical validity, this study employs a polynomial model incorporating cross-flow drag terms to approximate non-linear hull forces, extends propeller forces to four quadrants by modifying the thrust coefficient in the first quadrant, and adjusts rudder forces based on slip ratio.

To validate the proposed model, this study conducts free-running tests specifically designed for low-speed manoeuvring. Such tests, particularly those involving thruster operations, are rarely reported, making this study a valuable contribution. The experiments to comprehensively cover combinations of thruster, rudder, and propeller operations are designed, which ensures that the model is evaluated under diverse conditions representative of port manoeuvres. Then the experimental results are compared with numerical simulations using the simplified model. The comparison shows good agreement, confirming that the model accurately reproduces the essential

characteristics of low-speed manoeuvring motion. This outcome indicates that the proposed approach is suitable for constructing safety assessment environments for MASS.

A Robust Simulation Framework for Verification and Validation of Autonomous Maritime Navigation

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Abstract:

The maritime transportation sector is undergoing rapid technological transformation as global shipping activities continue to expand, and the availability of experienced seafarers declines. In response, Maritime Autonomous Surface Ships (MASS) are widely regarded as a viable solution to mitigate workforce shortages while improving navigational safety, operational efficiency and long-term cost effectiveness. Despite these anticipated benefits, MASS face several critical challenges that complicate their real-world deployment, particularly the need to operate reliably in adverse and unpredictable weather conditions. Extensive incident reports from the European Maritime Safety Agency (EMSA) between 2011 and 2024 indicate that over 60 percent of maritime accidents involve collisions, loss of control, groundings or contact events. Additionally, nearly 80 percent of grounding and contact incidents, along with approximately 70 percent of fatalities, are associated with severe weather conditions¹. General cargo ships exhibit the highest vulnerability in such scenarios, followed by roll on/roll off ferries, bulk carriers and tankers². These statistics highlight the need for rigorous testing and validation frameworks capable of evaluating MASS performance under realistic and unsafe conditions prior to large-scale deployment.

To address these gaps, this work presents an enhanced virtual simulation framework that builds upon the existing platform jointly developed by Texas A&M University and the American Bureau of Shipping (ABS)³. The expanded framework integrates a detailed environmental modeling suite that captures a spectrum of adverse weather conditions, including fog, rain, wind and wave dynamics, all rendered with high physical fidelity. To support geographically realistic testing scenarios, the framework incorporates bathymetry and traffic data from major ports in the United States, notably the Port of Houston and the Port of Los Angeles. Furthermore, the simulator models how adverse weather degrades sensor performance and situational awareness, providing realistic representations of radar clutter, camera occlusion, reduced visibility and impaired perception capabilities. These enhancements enable examination of the complex interactions between environmental disturbances, vessel dynamics and autonomous navigation algorithms.

The framework offers extensive user configurability, allowing them to manipulate weather parameters and maritime traffic configurations to evaluate MASS robustness across diverse operational scenarios. Integrated performance indicators facilitate systematic assessment of collision-avoidance behavior, path-planning efficacy and grounding-prevention performance. The incorporation of real-world bathymetric profiles further supports evaluation of MASS controllability and safety in shallow or congested waterways, strengthening the realism of grounding-related test cases.

Overall, the proposed simulation framework offers a high-fidelity, flexible and scalable platform for assessing MASS performance in complex maritime conditions. By enabling rigorous testing, objective performance evaluation and safe replication of adverse weather scenarios, the framework serves as a critical enabler for improving MASS reliability and accelerating their broader acceptance and adoption across the global maritime sector.

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Situation Awareness Through Shared Control: Safety-Assisted Remote Maritime Operations

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Abstract:

Remote operation of Maritime Autonomous Surface Ships (MASS) will remain an integral part of enabling highly autonomous operations in the near future. While recent work has shown improvements in situational awareness for ROC operators through advanced workstation design, critical safety support is still required when operators take direct control of the vessel. We argue that autonomy must remain in the loop during remote operations to help compensate for environmental disturbances that are difficult to perceive and communicate to the operator, such as drift effects from waves, wind, and currents. This challenge is particularly relevant in short-notice takeover scenarios, where the operator may not have sufficient time to fully assess the situation and environmental influences—potentially increasing the likelihood of hazardous actions. To mitigate these risks, safety functions must remain active even when a human operator is in the control loop.

This paper presents a shared-control architecture that integrates collision avoidance and velocity-direction constraints directly into the remote control loop as an invisible safety shield. The approach maintains full operator authority while automatically enforcing feasible-motion limits and safe directional behavior near static and dynamic hazards. These constraints are derived from both geofenced areas (e.g., quayside boundaries and restricted zones) and dynamic situational awareness inputs such as the detection of anomalous objects or nearby vessels.

The new system architecture builds on prior work in stability-assisted shared control, recently recognised as a finalist contribution in an IFAC conference, and advancements in velocity restrictions for autonomous motion force control. Here, the development is extended to ROC teleoperation through two main mechanisms: A feed-forward command feasibility filtering, which maps operator inputs to the nearest safe control vector when needed, and an adaptive safe-speed limitation, which reduces the permitted surge–sway velocity envelope based on hazard proximity and risk level. Operator commands are continuously blended with supervisory safety actions without noticeable latency. The aim is that the operator experiences natural telepresence with extra safety caution, where unsafe steering is not allowed, supporting transparency and trust in the control loop.

The concept is under integration and evaluation on the milliAmpere1 research ferry in Trondheim, Norway, using the newly developed Prometheus remote operation centre (as

disseminated in ICMASS 2025). Early testing demonstrates that the safety shield effectively prevents hazardous intent during both precision maneuvers and transit operations, while retaining controllability and minimising operator workload. A structured experimental campaign with expert operators is planned for December 2025/January 2026 to validate operational performance and indicate human-factor response under representative ROC conditions with remote steering.

The presented approach contributes toward safe MASS operations in urban waterways by providing a continuous safety net during remote control. Ongoing work includes coupling the remote safety assistance with optimal fallback guidance and digital-twin-based state estimation, which will be pursued as a complementary technical contribution for Fusion 2026.

Visual Rule-Guided Deep Reinforcement Learning for Autonomous Ship Navigation in IALA-Regulated Port Environments

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Abstract:

Safe and efficient autonomous navigation of Unmanned Surface Vehicles (USVs) in port environments is aimed at increasing operational efficiency and mitigating risks associated with human error. However, these operations are fundamentally constrained by high traffic density, complex multi-vessel interactions, and the strict requirement to comply with navigation regulations such as the International Regulations for Preventing Collisions at Sea (COLREGs) and International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) buoyage systems. Existing deep reinforcement learning (DRL) approaches for maritime autonomy often rely on simplified sensor data and lack the capability to integrate perceptual cues from IALA buoys. This limitation hinders the development of agents that can learn rule-consistent behaviors directly from vision. This creates a significant gap for safe, reliable, and verifiable deployment in regulated maritime waters.

To address this gap, this study proposes Visual Rule-Guided Deep Reinforcement Learning (VRG-DRL), a framework that integrates visual perception of IALA buoy colours with shared-policy multi-agent decision policies. The framework utilizes a Convolutional Neural Network (CNN) encoder to extract IALA (Region A/B) colour semantics from camera imagery. These visual features are fused with vector-based observations and processed within a shared-policy Proximal Policy Optimization (PPO) architecture. This multi-agent approach is trained jointly with COLREGs-compliant fixed-route Autonomous Surface Vessels (ASVs) to ensure robust decisions in dynamic traffic scenarios.

To validate cross-port generalisation and regulatory robustness, three container port simulation environments are constructed: Singapore (IALA Region A), Los Angeles (Region B), and Rotterdam (Region A). These environments feature distinct buoyage layouts, traffic densities, and IALA rule variations. These environments provide a rigorous benchmark. Extensive experiments demonstrate that VRG-DRL enables USVs to execute safe, rule-compliant, and goal-directed navigation and avoid collisions with dynamic ASVs. The results indicate that the shared-policy PPO improves training stability and policy transferability across heterogeneous port scenes.

This study presents a DRL framework that successfully integrates visual-semantic perception of IALA rules with multi-agent learning. The findings demonstrate the feasibility

to train agents to navigate based on regulatory markers, not just abstract waypoints. This approach produces auditable, rule-consistent behaviors that provide a direct technical basis for certification, an important step for practical deployment. Future work will focus on the transfer of these policies from simulation to real-world USVs and will address more complex conditions. This research will serve as a foundational component for the development of robust decision support systems and, ultimately, the phased autonomy of larger commercial vessels.

A Web-Based Virtual Test Environment for Autonomous Navigation Systems Validation

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Abstract:

Testing Autonomous Navigation Systems (ANS) in high-traffic port waters requires a platform capable of organising encounter scenarios, replaying vessel behavior & responses in dynamic maritime environments, interfacing with external decision-making modules, and supporting structured performance evaluation. This paper presents the architecture of a web-based Virtual Test Environment (VTE) developed for ANS testing in the Singapore Strait, one of the world's busiest waterways. The contribution is not a new collision-avoidance algorithm, but an extensible platform architecture that integrates browser-based visualisation, AIS-driven scenario management, backend vessel maneuverability simulation engine, and reporting workflows into an integrated test environment. The system adopts a modular layered design that separates operator interaction, application services, data persistence, and external ANS integration, enabling future incorporation of risk assessment, COLREGs compliance checking, and higher-fidelity vessel models.

PARALLEL SESSION 4: MARITIME CYBERSECURITY

Resilient Maritime Localisation Using 5G Non-Terrestrial Networks Against GNSS Spoofing and Jamming

Ma Yugang¹, Chin Francois Po Shin¹ and Sun Hongbo¹

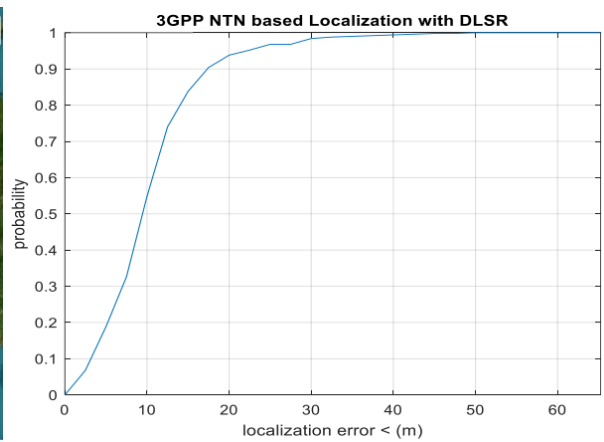
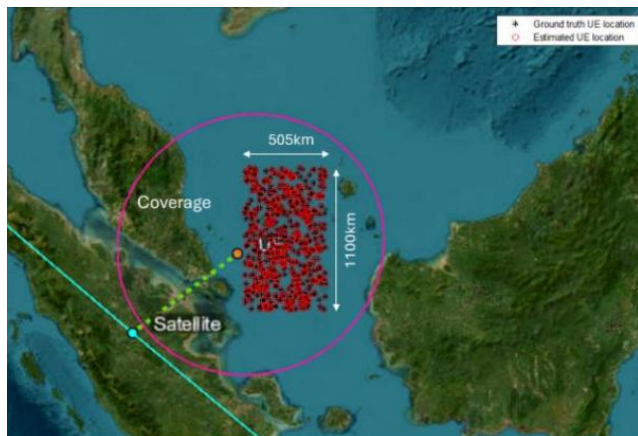
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Abstract:

Autonomous and smart vessels depend on accurate and resilient positioning to ensure safe navigation and berthing. However, Global Navigation Satellite Systems (GNSS) are highly susceptible to spoofing and jamming, leading to degraded or deceptive positioning information that can endanger maritime operations. To address this vulnerability, 5G Non-Terrestrial Networks (NTNs) have emerged as a complementary infrastructure that integrates low-Earth-orbit (LEO) satellites into the 5G ecosystem to provide global coverage and an independent positioning source. Despite rapid progress in 3GPP standardisation, current 5G NTN positioning approaches typically yield only kilometer-level accuracy when using single-satellite range with range and Doppler measurements, limiting their usefulness for maritime navigation.

This paper proposes a deep-learning-enhanced single-satellite localisation framework that substantially improves 5G NTN positioning accuracy. The method outperforms the typical method with Round-Trip Time (RTT) and Doppler (range-rate) measurements and satellite beamforming features, all of which are available within the 3GPP NTN standard. An AI model, called deep learning super resolution (DLSR), is trained to learn and correct the residual nonlinear mapping between the existing and projected high system setting to reach higher measurement accuracy and resolution. This effectively compensates for measurement noises, especially sampling uncertainty, beam pointing error and channel impairments.

The proposed algorithm achieves a localisation error below 29 m for 90% of the cases, with a root-mean-square error (RMSE) of 12 m using a single LEO satellite at an orbital altitude of 600 km. These results demonstrate that decameter-level vessel localisation is attainable even with a single 5G NTN satellite, making the method a viable GNSS-resilient solution for port and near-shore operations, where high reliability, accuracy, and security are essential for autonomous berthing and collision avoidance.



Storm Shield: A Semi-Markov-Driven Defense Against DDoS Attacks in NMEA 2000 Maritime IoT Systems

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Abstract:

The rapid evolution of digital technologies in maritime operations has underscored the critical need for tailored cybersecurity measures, particularly to mitigate Distributed Denial of Service (DDoS) attacks targeting essential communication protocols such as NMEA 2000. This paper proposes an innovative anomaly detection framework based on stochastic semi-Markov processes, specifically designed to strengthen the cybersecurity posture of Maritime Internet of Things (MIoT) systems deployed on modern vessels. The proposed model characterises the normal behaviour of NMEA 2000 traffic by modelling state transitions and sojourn times associated with key operational variables, such as message types, source destination patterns, traffic volumes and temporal inter arrival dynamics.

Once this baseline is learned, deviations from expected transition probabilities or dwell time distributions are used to flag potential DDoS activities in real time. In contrast to conventional threshold based or purely signature driven techniques, the semi-Markov formulation naturally captures the stochastic and time dependent nature of maritime network traffic. This capability allows the detector to distinguish between benign traffic bursts caused by legitimate operational conditions and malicious flooding patterns indicative of DDoS attacks, thereby reducing false alarms and improving operator trust. The framework is designed to operate at the edge of the vessel's network architecture, enabling local detection with low latency and limited computational overhead, which is crucial for resource constrained maritime environments and legacy onboard systems.

The proposed framework has been implemented and tested on NEAC Industry's maritime cybersecurity platform, using traffic captured from real vessels operating in coastal waters and offshore routes. Controlled DDoS campaigns were carried out against NMEA 2000 segments in a safe, isolated environment, enabling real time observation of attack dynamics and detector behaviour on operational data. In addition, the approach is evaluated using simulated NMEA 2000 datasets that emulate both normal operation and multiple DDoS attack scenarios, including flooding of specific PGNs, saturation of critical control messages and coordinated multi source attacks. Preliminary testing and early results suggest high detection efficiency, low error rates and stable performance under varying traffic loads and attack intensities, while the model also shows robustness to

noise and natural traffic variability, thereby helping to limit alarm fatigue for human operators on the bridge or in the control room.

Beyond its immediate application to NMEA 2000, the proposed methodology can be extended to other maritime and industrial communication protocols used in navigation, propulsion and cargo monitoring. By integrating probabilistic modelling, temporal dynamics and edge based deployment, this research contributes a proactive and adaptive cybersecurity mechanism that enhances situational awareness and supports continuous monitoring of vessel networks. Overall, the work represents a significant step towards more resilient MIoT architectures, providing ship operators, classification societies, system integrators and cybersecurity practitioners with a specialised tool to protect critical maritime systems against increasingly sophisticated DDoS or other threats.

Navigating the Gaps: Understanding AIS Data Reliability — A Big Data Framework for Analysing Missing Patterns

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Abstract:

The Automatic Identification System (AIS) serves as a cornerstone for vessel monitoring and regulatory oversight in global maritime traffic management. Missing AIS tracking data poses significant challenges to safety, operational efficiency, and regulatory compliance across global shipping networks, which generate terabytes of tracking data on a daily basis. While traditional approaches analyse small datasets using basic completeness metrics, the exponential growth in maritime data volumes necessitates scalable frameworks capable of processing millions of records while identifying systematic quality patterns.

This research introduces a novel big data framework for AIS track missing pattern analysis through a functional approach that integrates spatial location, temporal dynamics, and vessel characteristics. The methodology transcends traditional descriptive statistics by enabling quantitative analysis of data quality drivers, addressing fundamental limitations in maritime data quality assessment.

Applied to Hong Kong's port area, our framework processed over 473 million AIS messages from 42,000+ vessels across a complete annual cycle, completing monthly analyses within an hour using 40-core parallel processing. Key findings reveal systematic correlations between AIS station density and data reliability, significantly higher missing rates during overnight operations [00:00-12:00], and inverse relationships between vessel size and transmission quality.

This research establishes quantitative foundations for precision maritime analytics, enabling proactive data quality management that enhances decision-making capabilities for both industry stakeholders and regulatory authorities in the big data era.

Simulator-Based Visualisation of Cyberattack Effects for Maritime Cybersecurity Training

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Abstract:

Cybersecurity is an increasingly critical concern in the maritime sector as modern vessels rely heavily on interconnected navigation, sensor, and automation systems. The proliferation of ECDIS, radar, ballast control systems, and networked bridge components has expanded the attack surface, meaning cyber incidents can now degrade situational awareness, introduce false sensor data, or even impair ship stability. Given these risks, the maritime workforce must be trained not only in prevention but also in timely recognition and practical response to cyber events that occur on board.

Under this initiative, we developed and integrated a suite of cyberattack effect visualisations into a high-fidelity full navigation simulator to support hands-on training and assessment. The objectives were threefold: (1) reproduce representative cyber failure modes with realistic operational consequences, (2) allow instructors to inject and control those effects in real time, and (3) capture trainee responses for debrief and evaluation.

The selection of our implementation is from a range of representative attack scenarios such as manoeuvring unavailability caused by false trips, slowdown due to cyber induced ECU/safety PLC disagreement, jamming and spoofing of the ship's GNSS (Global Navigation Satellite System) connected navigation systems, Power Management System (PMS) blackout, loadshedding, ballast system manipulation. Ships are now heavily reliant on GNSS technology. GNSS pulses are weak and are therefore vulnerable to Jamming of a port or other congested waterway using small portable jammers. State-sponsored spoofing involves transmitting false signals that deceive receivers into locking onto them, posing a serious threat to GNSS and potentially leading vessels into dangerous waters. In this paper we present two in-house developed attack scenarios - Radar spoofing which injects synthetic or displaced targets to mislead navigational decision-making and the ballast attack which simulates malicious manipulation of ballast tank sensors and valves that produces asymmetric loading and dynamic stability degradation. The attack effects are implemented using the simulator's API: sensor-level hooks allow signal perturbation or replacement, and control interfaces modify actuator/plant models to emulate compromised control loops. We also developed a dedicated instructor control panel with a graphical interface to trigger, parameterise, and sequence attacks (e.g., onset timing, intensity, persistence), together with logging and timestamped event markers. All events,

sensor streams, and control actions can be recorded for replay and objective post-exercise analysis.

Cyber Attacks Against Remote Operations Centres: Risks and Legal Implications

Durmaz Fatih¹

¹University of Southampton, UK

Abstract:

In recent years, the growing use of autonomous ships is transforming the way maritime operations are conducted. At the centre of this transformation are Remote Operations Centres (ROCs), which function as hubs for monitoring, decision-making, and control. Through advanced human-machine interfaces, real-time sensor data, satellite communications, and automated systems, ROCs oversee vessel navigation, safety, and operational compliance. While these technologies promise increased efficiency and reduced risks to seafarers, the high level of digital connectivity and centralised control also creates serious cybersecurity vulnerabilities. As critical elements of the autonomous shipping system, ROCs may therefore become attractive targets for cyberattacks with potentially wide-ranging maritime, economic, and environmental consequences.

Cyber attackers may exploit ROCs using various techniques, including GPS spoofing, communication jamming, malware infections, data breaches, and system hijacking.¹ Such attacks can interfere with navigation, disrupt command systems, or allow unauthorised access to ship controls. In more serious cases, attackers may be able to seize effective control of an autonomous ship and hold it 'hostage', threatening to cause collisions, or even the sinking of the ship unless their demands are met. These scenarios raise important questions not only about maritime safety and security, but also about the ability of existing international legal frameworks to respond to cyber threats affecting maritime operations.

This paper considers whether cyberattacks targeting ROCs and autonomous ships can be addressed and punished under international law, with particular attention to the Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation (SUA Convention). It examines whether the Convention's offence-based framework is capable of covering cyber-enabled attacks that are carried out remotely and may originate far from the maritime domain. The analysis explores whether conduct such as remote interference with navigation systems, digital hijacking of vessel controls, or threats to destroy or endanger a ship can fall within existing SUA offences, even where no physical force is used and no attacker is present on board.

The paper also highlights key legal challenges, including difficulties in attribution, jurisdiction, and the required connection between the offence and the ship under the SUA

Convention. It argues that although the SUA Convention offers a more suitable legal basis than traditional piracy rules for addressing cyber threats to autonomous shipping, further interpretative development and regulatory clarification are needed. The paper concludes by emphasising the importance of international cooperation and legal adaptation to ensure effective accountability for cyberattacks against ROCs in an increasingly digital maritime environment.

Multilink Connectivity Framework for Seamless Switch-over

Goh Lee Kee¹, Cheng Wang Cho¹, Wong Kim Sing¹

¹Institute for Infocomm Research, Agency for Science, Technology and Research, Singapore

Abstract:

The maritime environment poses significant challenges for establishing stable and reliable communication. Factors such as harsh weather conditions, signal interferences and vast communication distances may cause severe disruption to communication signals. While there are different communication technologies (e.g. satellite, 5G, HF, VHF) that can be deployed in the maritime environment, each technology has its own strengths and weaknesses under different conditions and ranges. In order to ensure greater overall reliability, a mix of these different communication technologies may be preferred so that when one system using a particular technology is experiencing disruption, an alternative system using another technology can take over to ensure that a communication link is still maintained. For example, a vessel close to the shore may use 5G or WiFi for high-throughput data. However, once it sails further out, these links weaken and satellite systems such as Starlink or OneWeb become the primary option for communication. The ability and flexibility to switch from one system to another as the environment conditions changes is vital for constantly maintaining a communication link in order to ensure the safety and operational continuity in the maritime environment.

In today's communication systems, the different communication technologies are usually treated as separate networks. When a communication link switches from one system (e.g. 5G) to another (e.g. satellite), there are often changes in the network addresses and routing as the network traffic is re-routed from one system to another. In addition, higher-layer protocols may need to re-establish their sessions due to the changes in the network addresses. All these may cause some disruptions to the network traffic flows, resulting in momentary service drops. Even short disruptions affect real-time applications such as live video feeds, remote control of equipment, maritime surveillance and mission-critical data exchanges.

In order to achieve seamless data transmission across different networks, we developed a multilink connectivity framework that unifies different communication systems into one seamless experience. The framework establishes a virtual Layer 2 mesh overlay across disparate Layer 3 IP networks. Devices see each other as if they are in the same Layer 2 network even though the underlying connections between them are Layer 3 links. With this virtual overlay network, our framework keeps stable virtual connections between the devices in the network so that applications do not need to reconnect every time the underlying link changes. Our framework also tries to intelligently steer the network traffic

across the different networks such as 5G, Wi-Fi, satellite, or other links depending on the link quality. By monitoring the link quality continuously and switching paths proactively before disruptions occur, our framework ensures smooth handovers with minimal packet loss.

By focusing on reliability and practical use cases rather than specific protocols, our approach provides a vendor-agnostic, software-based solution that can be run on diverse hardware such as routers, switches and various end devices that can be used on board the vessels. This allows the vessels to set up a resilient communication backbone using various different communication systems.

Modeling and Engineering Cyber–Safety Causality in Autonomous Maritime Navigation

Yaman Sinem Getir¹

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Abstract:

The rapid advancement of Maritime Autonomous Surface Ships (MASS) necessitates a fundamental shift in how safety and security are managed. The rigorous analysis of specific causal chains linking security breaches to safety hazards is central to effective safety-security co-engineering. Managing these interdependencies poses a significant challenge, particularly in the complex operational environments of MASS, where sophisticated and unexpected cyberattacks can dramatically increase the risk of catastrophic safety hazards. Current safety and security analysis techniques often treat safety and security in isolation, failing to capture the dynamic, cascading effects of a successful cyber intrusion on physical systems and human-in-the-loop operations.

This research addresses this gap by investigating the effect of credible cyberattacks on the risk of collision in MASS using Structural Causal World Models (SCWMs), which use Directed Acyclic Graphs (DAG) to capture the complete causal pathway from cyberattacks to safety hazards. We illustrate the MASS-SCWM which specifically models an attack targeting the vessel's perception layer, such as an adversarial attack on the computer vision systems used for object detection and range estimation. The model traces the consequences from the initial security event (the exploitation of a vulnerability in the Machine Learning model's robustness) through the loss of data integrity for crucial navigational inputs (e.g., vessel size, speed, course and range). This integrity loss, in turn, is causally linked to a safety hazard (e.g., unsafe speed, latency in the manoeuvre, executing an improper manoeuvre), ultimately leading to the elevated risk of collision. This is particularly critical in MASS, where methods for avoidance and resilience are needed.

Leveraging the MASS-SCWM, we perform a quantitative sensitivity analysis. This analysis systematically quantifies how variations in key security parameters, specifically, the probability of a successful attack and the degree of system vulnerability, propagate through the model and impact the final probability of the collision hazard. The results yield crucial quantitative metrics for risk managers, demonstrating the relative criticality of specific cyber vulnerabilities in the context of operational safety risk.

On the Development of Scalable and Modular Ka-band SATCOM Terminal for Tropical Ocean

Qing Xianming¹, Tang Xinyi¹, Chin Francois Po Shin¹

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Abstract:

While L-band SATCOM links provide reliable services in all-weather conditions, the emerging Ku-band SATCOM links such as Starlink Maritime offers high throughput connections due to a larger available bandwidth. For the same area, the Ku-band terminal naturally brings antenna gain up by more than 15 – 20 dB as compared to L-band terminal. Soon, Ka-band MEO (SES O3b mPOWER) and LEO (Telesat and Kuiper) global constellations will start offering an even larger bandwidth for maritime applications in clear-sky conditions. There is a trend for ships to equip orchestrated SATCOM terminals that enable smooth and optimized connectivity using different bands (L/Ku/Ka) and with different orbits (LEO, MEO, GEO).

This talk will focus on the electronically steerable antenna (ESA) terminal development in Singapore for the upcoming Ka-band constellation. ESA technique is used to enable fast beam tracking capability required by LEO and MEO orbits while considering the pitch/roll movements due to sea conditions.

Firstly, the performance evaluation of the three bands (L/Ku/Ka) for their multi-orbit connections and the tradeoffs with size, power consumption, throughput and tracking requirements will be analysed in the context of tropical ocean. Ka-band terminal specifications will be highlighted. Secondly, two generations of Ka-band transmitting and receiving beam steering antenna modules with measurement results will be shared. This includes the latest results of a completely Singapore developed (including core chips) shared aperture Ka-band terminal module that can provide the minimum form factor. Because of the modular concept, the derived specification for Ka-band from the first part can be achieved by putting multiple modules into different shapes. Lastly, the roadmap of the next generation terminal with multiple bands access and higher TRL will be discussed.

PARALLEL SESSION 5: SMART SHIPS

From CONOPS to Approval: Regulatory and Commercial Pathways for Demonstrating Autonomous Inland Shipping between Terneuzen and Ghent

Mørkid Odd Erik¹

¹SINTEF Ocean AS, Norway

Abstract:

The transition to autonomous inland shipping in Europe requires not only technical maturity but also collaborative, transparent, and reproducible approval processes. This paper presents a structured approach to securing permits for an autonomous vessel demonstration on the cross-border waterway between Terneuzen (NL) and Ghent (BE), a milestone within the AUTOFLEX project.

Rather than focusing solely on regulatory frameworks, we analyse both the legal requirements and the commercial acceptability of risk, recognising the interplay between hard governance (laws, decrees, administrative procedures) and soft governance (stakeholder trust, market readiness, and operational risk tolerance). The Flemish framework, based on Article 70 of the Scheepvaartdecreet, provides a model for testing autonomous systems under temporarily adapted legal conditions, while Dutch authorities emphasise risk acceptability in practice.

To ensure balance and transparency, the paper integrates perspectives from authorities and stakeholders through targeted interviews, capturing their views on challenges in the approval process. Approval is structured around a Concept of Operations (ConOps) in accordance with IEEE 1362, complemented by a maritime adaptation of the Specific Operations Risk Assessment (SORA) method. Together with validation data, these elements form a Comprehensive Safety Portfolio (CSP) that supports both regulatory and commercial decision-making.

The result is a blueprint for future pilot projects that bridges innovation, governance, and market viability, laying the foundation for sustainable deployment of autonomous inland vessels across Europe.

Agent-Based Multimodal Retrieval and Regulation Analysis for Automated Ship Design Compliance

Huang Yi-Lun¹, Weng Wei-Chu¹

¹Department of Systems Engineering and Naval Architecture, National Taiwan Ocean University, Taiwan (R.O.C.)

Abstract:

With the advancement of artificial intelligence and digital-twin technologies, the demand for 3D assets and automated regulatory verification is increasing across intelligent manufacturing. However, current digital workflows still lack an integrated mechanism for processing engineering documents, multinational ship-classification rules, and design data, leaving ship-survey and design-review tasks predominantly manual, time-consuming, and susceptible to regulatory misinterpretation.

This research presents a ship-regulation management and semi-automated compliance-review framework that integrates vision-language models with agent-based retrieval (Agent-RAG). The system employs YOLOv11 for layout interpretation and element segmentation, while the Qwen3-VL model family provides multimodal semantic understanding and relational extraction from scanned PDF regulations. Through this processing pipeline, unstructured rule documents are converted into a structured, machine-interpretable, and semantically searchable regulatory knowledge base.

To support engineering applications, the framework incorporates semantic compression, hierarchical indexing, and adaptive retrieval to reduce token usage and enable secure on-premises long-document processing. Agent-based task planning further automates strategy selection, cross-society rule comparison, and traceable reasoning. The framework also provides a foundation for digital-twin applications, including automated drawing-to-regulation checks, structural compliance evaluation, and regulation-driven design workflows in shipbuilding and defense engineering.

Adaptive Design and Operations for Next-Generation Ships under Uncertainty via the MODE Simulation Platform

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¹The University of Tokyo, Japan

²Kahramanmaras Istiklal University, Turkey

Abstract:

The maritime industry is entering a period of structural transformation driven by accelerating decarbonisation requirements, increasing volatility in fuel prices and metocean conditions, rapidly evolving regulatory frameworks, and the emergence of new technologies such as wind-assist propulsion and autonomous navigation. Under such circumstances, traditional ship design and operation methods that rely on fixed assumptions or historical trends are becoming increasingly insufficient.

Maritime and Ocean Digital Engineering (MODE), an industry–academia consortium composed of 18 companies and hosted at the University of Tokyo, has been established to address these challenges. MODE defines its integrated Simulation Platform as a foundation for collaboratively evaluating the technologies and products held by each company across the entire ship lifecycle, and for enhancing system-level value through cross-industry co-creation. By enabling multi-stakeholder collaboration, the platform makes it possible to assess integrated maritime systems in ways that were previously unattainable through siloed approaches.

This study leverages the MODE Simulation Platform to explore three representative use cases by explicitly incorporating exogenous uncertainties surrounding ship operation. As a case study, we apply the framework to a VLCC equipped with wind-assist propulsion and conduct scenario-based simulations. First, we investigate how optimal ship and operational solutions shift when external conditions such as metocean variability, fuel prices, regulatory scenarios, and technological progress are altered. Mapping the decision space under these uncertainties enables the identification of solutions that remain robust or adaptive across divergent futures. Second, we examine architecture design processes for next-generation vessels and analyse which design variables should be fixed early and which should intentionally remain flexible. The results show that exploring multiple subsystems concurrently expands the attainable Pareto front and yields higher-quality solutions compared to staged or sequential exploration, thereby informing low-regret architectural strategies that minimise rework across alternative scenarios. Third, we evaluate how combinations of emerging technologies generate synergistic effects, enabling the identification of high-value technology bundles and supporting the construction of effective R&D portfolios.

Overall, the results illustrate the potential of the MODE Simulation Platform as a foundation for digital engineering and strategic planning in the maritime sector. The platform aims to support advanced design and decision-making under deep uncertainty by integrating diverse technologies, stakeholder perspectives, and future scenarios.

Deep Reinforcement Learning Based Safety-critical Scenario Generation for Autonomous Ship Digital Testing

Wang Hongwei^{1*}, Fu Xiuju¹, Sun Junze², Wang Fengde³, Xing Yingying³

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*Corresponding Author: Wang Hongwei

Abstract:

The development of Maritime Autonomous Surface Ships (MASS) represents a transformative shift in maritime transportation, where digital testing systems play a pivotal role in evaluating autonomous behaviors under complex and safety critical conditions. Such systems, incorporating software simulation, scenario libraries and agent–environment interaction, are essential for addressing challenges arising from environmental complexity and rare but high risk events. While existing research predominantly focuses on collision avoidance scenarios from the own ship perspective, few studies investigate adversarial or attacking ship behaviors that are crucial for stress testing MASS intelligence. This study introduces an end to end framework for generating safety critical scenarios from the attacking ship perspective using deep reinforcement learning (DRL). Real world trajectory and geographic data from the Strait of Singapore are leveraged to initialise realistic interactions, covering head on, overtaking and crossing maneuvers. Scenario evaluation integrates collision related indicators such as Time to Collision (TTC) and risk metrics derived from the Closest Point of Approach (CPA) to assess scenario severity and behavioral fidelity. Experimental results show that the proposed framework produces diverse and high quality critical scenarios that enhance the realism, challenge level and robustness of MASS digital testing systems. Overall, this work provides an AI-driven scenario generation methodology that enriches digital testing environments and supports the development of more reliable and resilient autonomous vessel systems.

Turku University of Applied Sciences Testbed for Resilient Uncrewed Surface Vessels

Paavola Jarkko¹

¹Turku University of Applied Sciences, Finland

Abstract:

Turku University of Applied Sciences is a hub for developing intelligent systems for autonomous operation in maritime domain. Turku archipelago provides unique and realistic conditions for experimentation and validation of autonomous systems.

Our research infrastructure includes the test vessel eM/S Salama and a dedicated remote operations centre, enabling real-time monitoring and control over wireless communication links. A key focus area is resilient communications: ensuring reliable, secure, and low-latency connectivity for autonomous and remotely operated systems in dynamic and harsh environments. This includes multi-link communication architectures, redundancy, adaptive networking, and robust operation under degraded or contested communication conditions.

PARALLEL SESSION 6: CARGO OPTIMISATION

Preventing Collisions with Critical Port Infrastructure: An Incident-Driven Approach to Designing a Shore-Based Assistance System

Feuerstack Sebastian¹, Mentjes Jan¹, Zhao Liangbin², Wang Ke², Fu Xiuju², Steger Christian³, Bathmann Marvin⁴

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²Agency for Science, Technology and Research, Singapore

³Institute for Marine and Atmospheric Research Utrecht, Netherlands

⁴Marivation GmbH, Oldenburg, Germany

Abstract:

While serious maritime accidents are rare, minor accidents or near misses are becoming increasingly common. The consequences are serious: in addition to economic damage to the ship and infrastructure, they can result in environmental damage due to leaking oil or personal injury. In 2024, a dredger collided with a stationary bunker vessel in Singapore's port waters, spilling about 400 tons of oil and causing widespread slicks across multiple shorelines¹, while earlier this year an oil tanker collided with an offshore supply vessel entering Cuxhaven Harbor in Germany, leaking approximately six cubic meters of marine fuel². According to accident reports of protection and indemnity clubs (P&I), on the other hand, most accidents occur with static infrastructure³. Additionally, it is assumed that a high number of such cases unreported, as most minor damages aren't reported or are unnoticed. The causes are often human error due to a lack of situational awareness to monitor the immediate vicinity of the ships⁴. For example, when entering port areas, there is no visibility from the ship's side, as infrastructure interferes with or obscures sensors such as radars and cameras.

Collisions with infrastructure occur in confined spaces inside ports that are navigationally challenging, such as port or lock entrances. Adverse wind or current conditions can also increase the frequency of incidents. Due to the limited geographical area in which incidents occur and therefore in which assistance is required, the automation islands concept can be applied. Automation islands are geographically limited and land-based assistance systems that support certain automation processes⁵. However, a designing such a sensor system is a challenge, as it must be specifically tailored to the location, weather conditions and navigational factors.

This paper presents a concept for safe maritime automation islands to support navigators when navigating in confined areas. This paper builds on the berthing assistance system SmartKai developed at the German Aerospace Centre. The shore-based system supports navigators with high-range LiDAR sensors (up to 300m under adverse weather

conditions), that determine distance and speed information in relation to static infrastructure. Within this paper, large-scale AIS-based modeling of berthing behaviour and the analysis of vessel trajectories passing near static infrastructure are first conducted to characterise vessel–infrastructure interaction patterns in confined port areas. Building on these results, a data mining task using IHPC’s near-miss case detection system is then carried out to identify unreported near-miss or minor incident cases and to provide insights for pinpointing critical areas within a German harbor. Through this combined analysis, locations with a high likelihood of incidents involving static infrastructure are identified. Next, the analysis examines the geographical area requiring assistance and how shore-based sensors can fully cover it. The evaluation is done by using a LiDAR sensor simulation. Different sensor configurations and locations are examined, leading to a trade-off analysis between the proposed setup and alternatives.

References:

1. [Fuel Spill on the Coast of Singapore After Collision Between Dredger and Bunker Vessel](#)
 2. [Fuel Spill in Germany’s Elbe River After Collision Between Tanker and Offshore Vessel](#)
 3. [A Survey of Accidents in Ports](#)
 4. [P&I Loss Prevention Bulletin](#)
 5. [Towards MASS-Ready Ports: Mitigating Blind Spots with Local Sensor Systems \(LSS\)](#)
-

Working Together is Success: Human-Machine Teaming to Increase the Use of Calculated Shipping Routes to Reduce Emissions

Sobey Adam¹, Yuen S.¹, Kommers C.¹, Young D.², Grudniewski P.A.²

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Abstract:

AI is rapidly transforming maritime operations. New approaches are being developed that provide a better understanding of the environment and how the vessels behave. These approaches allow us to change the routes the vessels take and to optimise the setup, for example the trim and draught. One of the earliest tools available were Voyage Optimisation tools that calculate the route the vessel should take. These tools account for the weather and currents, to optimise the speed, route and vessel trim and draught. However, these tools only recommend a route that should be followed, the ship routers and/or ship's captain decide on the final route that should be followed. So while it can be demonstrated that the route generated from Voyage Optimisation Software leads to a more efficient route, these routes are not always used. It's therefore important to integrate the software into the routing workflow, to reduce emissions. This means that the route selectors need to trust the tool. This presentation will focus on the development of a module to explain why the tool selected the final route to the end user. The first stage uses statistical methods to determine the difference between all of the routes generated. This allows isolation of the key features from the optimal route and how it differs from those routes that are slower or use more fuel. These key features then need to be provided to ship's captains or routing specialists in a manner that allows integration of the tool into working practices, augmenting the skills of the specialist. To do this a series of interviews are performed to determine how best to communicate the results to the specialist, this focuses on the language that should be used to provide easiest understanding and the length of the communication that needs to balance easy communication and depth of information. Finally, templates are generated from these interviews that combine the key features from the analysis to give the user this information in a clear manner.

MARKS: An AI-Driven MAritime Risk Knowledge System (MARKS) for Disruption Event Profiling and Supply Chain Impact Projection

Wang Ke^{1#}, Jin Jiongchao¹, Tan Xue Lin¹, Yin Xiaofeng^{1*}, Fu Xiuju^{1*}, Zhou Nina^{2#}, Jiang Ridong², Tharini De Silva², Ng Eddie³, Shobana Ravisankar³

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#Equal Contributions

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Abstract:

Maritime shipping is paramount to global trade. However, maritime shipping disruptions, ranging from canal blockages, extreme weather events, to geopolitical conflicts, have become more frequent and increasingly impactful on global supply chain resilience. While huge volumes and multiple sources/modals of data are associated with the disruptions, due to the lack of systematic framework and difficulty in handling with big and multi-modal data, existing analytical tools typically limited themselves in isolation and rarely fuse these multi-modal data sources into structured, holistic, and real-time decision support for maritime shipping, port operations and logistics management.

To address this gap, this paper presents the **MAritime Risk Knowledge System (MARKS) framework**, in which an AI-based system aims to support comprehensive maritime disruption analytics and evaluation. It leverages the latest AI development including generative AI, predictive AI and agentic AI development to intelligently convert multimodal maritime and supply chain data into structured risk event profiles, extracting insights from historical disruptions, and generating interpretable impact projections across cargo flows and port networks. With that, MARKS is designed to support timely decisions under volatile maritime shipping by improving early warning capability and strengthening risk-informed operational planning.

The unique features of the proposed system included our proposed “6R” maritime disruption knowledge base schema, multi-layered knowledge structure and AI-driven modules for timely disruption insight extraction and evaluation etc. Especially, the three core layers are structured with Data Layer — Multi-modal data fusion and disruption profiling using the “6R” maritime disruption knowledge base schema; Knowledge Layer — AI-driven insight extraction from structured historical events; Intelligence Layer — LLM-enabled interactive risk analysis and impact projection.

Our proposed “6R” framework (Recognition → Rooting → Reporting → Range → Result → Response), which enables comprehensive representation following disruption

types categorised systematically. This ensures systematic extraction of event attributes, causal factors, affected regions, and operational consequences.

By bridging data silos and operationalising maritime disruption analytics, this work provides a practical and extensible AI-based architecture that transforms fragmented maritime and supply chain signals into actionable risk intelligence. MARKS enhances resilience planning, enables proactive cargo flow management, and supports the development of next-generation, risk-aware maritime supply chain digitalisation.

Dynamic Navigation and Port Call Optimisation in Real Time

Fjortof Kay Andre¹, Dynaport Partners²

¹SINTEF Ocean, Norway

²Norway

Abstract:

The European maritime transport policy recognises the importance of the waterborne transport systems as key elements for sustainable growth in Europe. However, if one is to succeed with following the pathway to net zero emissions by 2050, more energy-efficient ship and port operations are crucial. Looking at today's operations, the numbers speak for themselves since round 15 percent of ships' greenhouse gas emissions are associated with port operations. In addition, there is untapped potential to reduce emissions at sea by around 20 percent.

Hence, this paper will focus on how different aspects of voyage and port call optimisation can play a vital role towards goal achievement. To succeed it will be necessary to develop new knowledge, processes and technology, where ships have increased possibility to align their operations with ports and terminals. This includes optimisation of arrival time at port, as well as optimisation of the port call process itself. It also rests upon industry adoption, implementation and actual use of the solutions developed. Today however, the prevailing operational practice is commonly referred to as "the hurry up and wait syndrome". Hence, one main objective of the EU-funded DYNAPORT project, is to demonstrate how "just-in-time" arrival for ships can be facilitated and thus show how substantial port call optimisation could be realised through seamless digital coordination between ships and ports.

As such, the paper will elaborate on how the project has developed technologies for decision support and information management as well as refer to demonstrations of the potentials inherent in the technological achievements. These include among others, a blueprint for integrated port cooperation, a voyage optimisation module for multi-party cooperation and end-to-end voyage optimisation tool and how nautical safety is achieved through improved coordination and prediction of traffic pattern. Essential building blocks in this context are contributions and developments of standards for communication and information exchange, also covering messages, API (Application Programming Interface) development, and electronic signature system.

In terms of impact, early results are already promising for automatic machine-to-machine data exchange between the vessel and the port. These results show that significant improvements in the port call process are possible, replacing multiple data entries and several attachments often done by email. They also show how a ship can reschedule its

voyage – and adapt its speed according to, among other factors, the traffic pattern at port of arrival, and terminal operators suggested time of arrival, which is then coordinated with the other stakeholders involved in the Port Call. Thereby realising more energy efficient operations – tapping into the concept of just-in-time operations. On the more commercial side, the paper will also shed light on how operational changes have an impact on various stakeholders involved, either in terms of cost and/or benefits, but also how to handle such changes due to factors both under and/or beyond the control of the master and ship owner.

Integrating Agentic AI into Maritime Logistics: Towards Autonomous, Sustainable, and Resilient Port Ecosystems

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Abstract:

The maritime and port sectors are undergoing a profound digital transformation driven by the pursuit of greater efficiency, sustainability, and resilience. In this context, Agentic Artificial Intelligence (Agentic AI) has emerged as a promising paradigm that leverages multiple interconnected autonomous agents capable of collaborating, planning, and adapting dynamically to achieve complex goals with minimal human supervision. These systems integrate diverse data sources, stakeholders, and objectives into a coherent decision-making framework through reasoning, memory, and self-organisation.

Despite its transformative potential, the application of Agentic AI in the maritime sector remains in its infancy, with limited research currently available. Agentic AI has the capacity to enhance efficiency, sustainability, and resilience in environments involving multiple actors, heterogeneous data, and interconnected processes typical of port operations. By autonomously integrating diverse data streams and optimising decisions across multiple objectives, Agentic AI presents significant opportunities to improve coordination, performance, and adaptability across the various services that define modern smart port systems. A holistic overview of these functional services is illustrated in Figure 1.

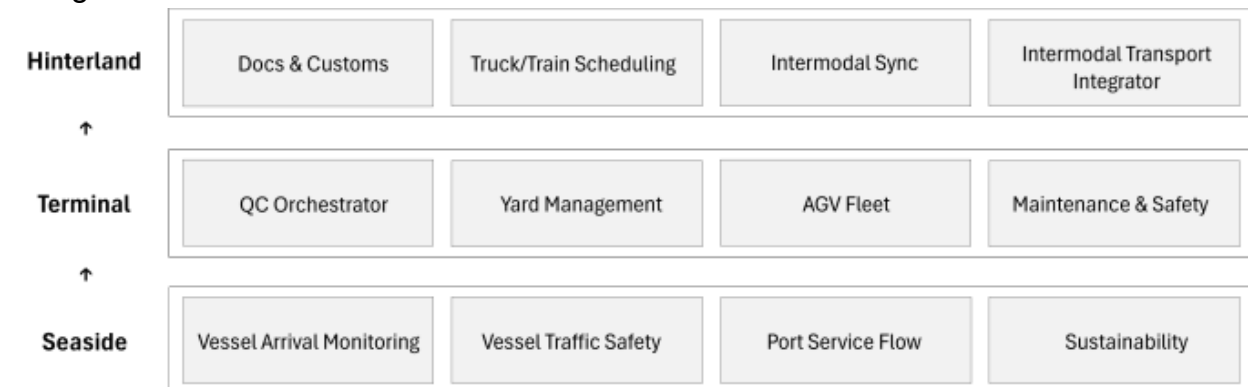


Figure 1: A holistic view of functional services for a Smart Port

This article aims to explore the potential benefits of Agentic AI for the maritime 31 domain and port logistics, as well as to outline the workflow system of the proposed 32

applications. Several use cases illustrate its applicability, including climate risk mitigation logistics and operations management, and the development of digital and green corridors that support energy-efficient routing and carbon monitoring. Additional applications are discussed in environmental management, such as energy optimisation, emission control, waste handling, and ecosystem protection, as well as in cybersecurity. An example of the proposed workflow is illustrated in Figure 2.

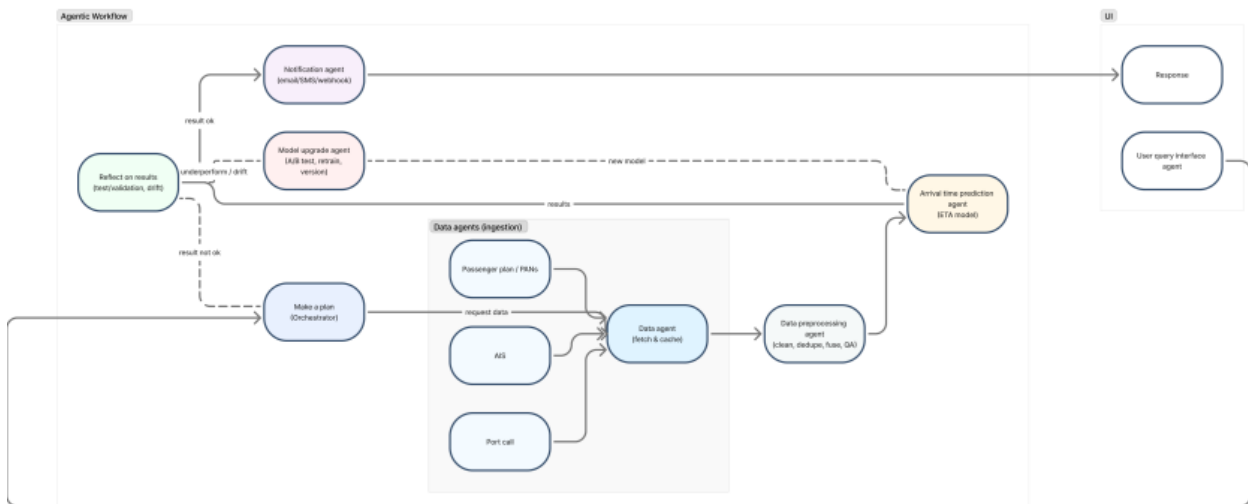


Figure 2: Agentic AI workflow system for vessel arrival monitoring, considering port authorities and port service providers as end users.

While Agentic AI can significantly improve the efficiency and sustainability of port operations, its implementation introduces complex challenges. These include technical integration, data governance, security, and financial considerations, which require collaborative approaches among all port stakeholders. The latter part of this study focuses on identifying these challenges and proposing strategies for their effective management to ensure a responsible and inclusive deployment of Agentic AI within the port and maritime ecosystem.

The study demonstrates that although Agentic AI is a nascent field, it holds great promise for the logistics sector and, in particular, for ports, where diverse stakeholders combine multiple information sources and pursue varied objectives. By connecting current AI and automation applications across seaside, hinterland, and terminal areas, Agentic AI systems can achieve broader objectives and generate new value.

PARALLEL SESSION 7: SMU MARITIME THOUGHT LEADERSHIP: STAKEHOLDER INTEGRATION – TOWARDS A FUTURE MARITIME ECOSYSTEM EMPOWERED BY AI

SMU will convene a maritime thought leadership session on 23 April, Thursday from 8am to 12.30pm on Stakeholder Integration - towards a future maritime ecosystem empowered by AI.



MARTIN JES IVERSEN
MPA Professor, SMU
Associate Professor,
Copenhagen Business School



JAKOB BRIX TANGE
Ambassador
Royal Danish Embassy



KENNETH LIM
Board Member, SMI and
Ministry Chief Information Officer,
Ministry of National Development
Singapore



NG YI HAN
Director (Innovation, Technology and
Talent Development),
Chief Transformation Officer,
Maritime & Port Authority of Singapore



SAKURA KUMA
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Stakeholder Integration - Towards a Future Maritime Ecosystem Empowered by AI

The integration of maritime stakeholders through digitalisation has taken place for the last 15-20 years - but in an accelerating pace. It is notable how for instance vessels have been connected to shore through low orbit satellites including the StarLink and the OneWeb network in the last 2-3 years. In this conference we discuss the consequences of the increasing stakeholder integration through digitalisation with a specific focus in the discussion: AI.

AI change the bar for implementation of digital solutions because in principle any decisions can be empowered instantly by massive data generation at relatively low costs (Lambrou, 2025). What we face with AI in the maritime sector is ultimately the integration of past (collective) experiences into present (individual) decisions (Iversen, 2025).

Our main purpose of this conference is to investigate the consequences of new AI-driven transactions in shipping. We look at internal processes in the maritime companies as well as on the relations between maritime companies and customers or between public authorities and private actors.

The overall question is to what extent AI changes the fundamental logics of the maritime ecosystem – and in cases where it does, what implications does it have for the stakeholders of our industry.

The SMU Maritime Thought Leadership Conference will invite two keynote speakers and further explore the topics in-depth in two themes:

Theme 1: AI Driven Transformations

Theme 2: Changing Transactions Through AI

Key-note: Towards a New Maritime Ecosystem

Time	Programme
8.00am – 9.00am	SMU Breakfast Networking (with SMRC x MTEC/ICMASS Conference delegates)
8.30am – 9.00am	Registration (Seating on first-come-first-serve basis)
9.00am – 9.05am	<p>Welcome Address</p> <p>Professor Marcus Ang, Academic Director and Track Coordinator, International Trading Institute, Singapore Management University</p>
9.05am – 9.10am	<p>Opening Note</p> <p>Ambassador Jakob Brix Tange, Embassy of Denmark in Singapore</p>
9.10am – 9.25am	<p>Introduction to the session and motivation of the theme "Stakeholder Integration - Towards a Future Maritime Ecosystem Empowered by AI"</p> <p>MPA Professor Martin Jes Iversen, MPA Professor in Maritime Business, Singapore Management University, and Associate Professor, Copenhagen Business School</p>
9.25am – 10.20am	<p>Keynote: Towards a New Maritime Ecosystem</p> <p>Mr. Kenneth Lim, Board Member, Singapore Maritime Institute, and Ministry Chief Information Officer, Ministry of National Development Singapore</p> <p>Mr. Ng Yi Han, Director (Innovation, Technology and Talent Development / Chief Transformation Officer), Maritime & Port Authority of Singapore</p> <p>Questions & Answer Session (10-minutes)</p> <p>Break (10-minutes)</p>

Time	Programme
10.20am – 11.10am	<p>Theme 1: AI Driven Transformations</p> <p>Ms. Sakura Kuma, Executive Officer, Mitsui O.S.K.Line Ltd and Managing Director, MOL (Asia Oceania)</p> <p>Mr. Jan Simon, Vice President IT and Digital, Hafnia</p> <p>Panel Debate and Q&A (10-minutes)</p>
11.10am – 12.30pm	<p>Theme 2: Changing Transactions Through AI</p> <p>Associate Professor Ms. Agnieszka Nowinska, Aalborg University Business School, Denmark</p> <p>Dr. Ms. Maria Lambrou, Professor, University of the Aegean, Department of Shipping, Trade and Transport, Chios Island, Greece</p> <p>Dr. Hyerim Bae, Dean, Graduate School of Data Science, Pusan National University, South Korea</p> <p>Panel Debate and Q&A (15-minutes)</p>
12.30pm	<p>Networking lunch (with SMRC x MTEC/ICMASS Conference delegates)</p>

PARALLEL SESSION 8: SMART SHIPS

Situation Awareness by Design: Consensus-Based Interface Design for Maritime Teleoperation

Gusev Alexey¹

¹Norwegian University of Science and Technology, Norway

Abstract:

Early visions of Maritime Autonomous Surface Ships (MASS) were dominated by the idea of fully autonomous vessels with minimal human involvement. In practice, however, current MASS concepts have re-introduced humans into the loop as remote operators, supervisors, or fallbacks when autonomy reaches its limits. This makes the remote operation centre (ROC) and its graphical user interface (GUI) a primary safety barrier rather than a secondary concern. Existing research and trials have shown that poor GUI design increases operator fatigue and adversely affects situation awareness by fostering so-called “situation awareness demons” (e.g. attention tunnelling, requisite memory traps, information overload, misplaced salience, complexity creep, errant mental models), which directly threaten the safety of the operation. Even within human-centred design (HCD) processes, operators often have limited input in the GUI’s content and structure. As a result, ROCs frequently present complex, information-rich interfaces with many underutilised features and widgets, which tend to overload operators with additional data instead of highlighting the information they need to control the vessel safely and efficiently.

This study investigated the effects of a personally customised GUI on teleoperation performance in a maritime ROC, compared to a default, expert-designed GUI baseline, and examined the importance of different information requirements (widgets, view layouts, camera streams, controls). The work was carried out in two phases: a prior co-design phase and an experimental trial phase. In the first phase, a focus group with experienced seafarers identified the most critical aspects for maritime teleoperation in relation to content, views, controls, and layout. These insights were then used to construct both an HCD default layout and a customisable interface that allowed each captain to build their own GUI. In the second phase, we conducted full-scale experiments using a shore-based control centre and a small passenger ferry connected through a low-latency communication pipeline, involving multiple professional seafarers. Each captain constructed their own GUI and then performed A/B, within-subject teleoperation runs comparing their custom layout with the default GUI during realistic operations.

Teleoperation performance is evaluated through a mix of objective and subjective measurements: situation awareness (SPAM), mental workload (NASA-TLX), passenger comfort ratings, operational performance (e.g., time, route keeping, docking, safety events), and eye-tracking-based visual scanning patterns. Customisation was expected to support faster familiarisation, better alignment with individual strategies, and lower cognitive load in demanding situations. Across captains, the resulting layouts also provide heat-map-style patterns of component placement and camera/view configuration,

indicating how information is prioritised in practice and informing an improved default layout. Overall, the study addresses whether a user-customised GUI can lower mental workload, enhance situational awareness, and improve operational performance in teleoperated passenger vessel operations. The results are also expected to inform GUI design guidelines for maritime teleoperation and future MASS control centres.

Considering the Intended Behaviour in Evaluating the Rule Compliance of MASS

Wetzig Nina¹, Austel Ann¹, Westphal Bernd¹

¹Institute of Systems Engineering for Future Mobility German Aerospace Center (DLR) Oldenburg, Germany

Abstract:

There is a rising interest in the development and use of Maritime Autonomous Surface Ships (MASS). To reduce risks in MASS operation and interaction amongst each other and with human operated vessels, safety needs to be evaluated before deployment. Vessels of all degrees of automation need to be able to comply with maritime traffic rules, such as COLREG rules, to avoid accidents and be predictable for the human operators of the vessels the MASS interacts with. A method to evaluate a MASS for rule compliance is the approach of scenario-based testing. Here, the MASS performs a set of scenarios, which are deemed relevant to demonstrate rule compliance, and each performance is then evaluated against the corresponding requirement derived from the rule. A scenario is passed, if the MASS acted in compliance with the rule and failed if the behaviour was in violation of the rule.

To objectively evaluate the rule compliance during scenario-based testing, there is the need to objectively specify the requirements stated by the rules. In previous work we specified COLREG rules regarding behaviour in and around TSS (Traffic Separation Schemes) using MTSCs (Maritime Traffic Sequence Charts). We implemented specifications of TSS rules in our monitoring tool, that acts as a plugin for a maritime traffic simulation, with the intention to support the evaluation of rule compliance of simulated MASS's behaviour. A limitation of that monitoring tool is, that while it assesses whether a MASS's behaviour is satisfying or violating the specification it is evaluated for, the results imply nothing further about how satisfying this particular specification can be interpreted. There might be instances where a MASS is satisfying the specifications for more than one rule, or instances where a MASS is satisfying the specifications of one rule but not the specifications of the rule it intends to follow.

In this work we discuss means of interpretation for the evaluation of simulated MASS's behaviour in regard to MTSC specifications. In particular we describe how to include knowledge about the MASS's intended behaviour (we here refer to it as the MASS's intention) and how to interpret the results of our monitoring tool in terms of the intention. We demonstrate how considering the MASS's intention is helpful for deriving a meaningful interpretation for the results of an evaluation of rule compliance. Including the knowledge about intention allows us to not only evaluate if any specification has been satisfied but to determine if the MASS's intended behaviour has been performed correctly. We show with a set of examples regarding COLREGs for TSS, how including intention enables our monitoring tool to provide an assessment about whether the rule concerning the intended behaviour was followed correctly by the MASS.

Computer Vision Based Early Detection of Container Loss at Sea

Lall Vishakha¹, Wu Kaiwen¹, Capt. Pinto Stanley S², Capt. Peng Chu Xing²

¹Centre of Excellence in Maritime Safety, Singapore Polytechnic, Singapore

²Pacific International Lines, Singapore

Abstract:

Containerised shipping forms the backbone of global trade, yet container loss at sea remains a persistent and costly safety, environmental, and operational challenge. Despite strict adherence to the Cargo Securing Manual (CSM) and routine lashing inspections, dynamic maritime conditions such as vessel motion, wind loading, and severe sea states can progressively loosen lashings, destabilising stacked containers and leading to overboard losses. The consequences are significant: multimillion-dollar cargo and insurance losses, navigational hazards from drifting containers, and marine pollution from unrecovered debris.

With the International Maritime Organization's (IMO) new mandatory reporting requirements under SOLAS amendments for lost containers taking effect in 2026, there is an urgent need for reliable, evidence-based monitoring and early detection systems to prevent such incidents. However, existing camera-based maritime safety systems focus primarily on fire detection, crew monitoring, or general safety compliance and existing sensor-based systems that measure stability, ballast tank and structural motion are cost intensive and disruptive, thereby lacking dedicated, low-cost, and retrofittable solutions for detecting container instability.

This study addresses that gap by developing a computer vision-based early detection system for container destabilisation using existing onboard camera infrastructure. The proposed system combines segmentation and optical flow motion analysis to detect abnormal container movements in real time, enabling early intervention before catastrophic loss. The technical framework integrates three core components:

1. **Segmentation:** A deep learning segmentation model (YOLO v7 seg) isolates individual container stacks from the background.
2. **Motion Tracking:** The optical flow algorithm (Deep Sort) tracks individual containers across video frames and features extracted on the tracked objects quantifies relative motion.
3. **Anomaly Detection:** Temporal modelling of container movement analyses motion sequences to distinguish normal vessel-induced oscillations from progressive instability, providing early warning.

Model training and validation utilise live and historical voyage footage supplied by Pacific International Lines (PIL), including documented instances of container instability under varying weather and lighting conditions.

The system aims to deliver actionable early alerts to support two types of interventions: (i) crew tightening of lashings in safe conditions and (ii) navigational adjustments during normal and adverse weather to mitigate rolling and instability risks.

Ultimately, this project pioneers a practical, scalable, and safety-critical innovation for the maritime industry, advancing early detection, traceability, and compliance with the upcoming IMO container loss reporting mandate. By enabling proactive risk mitigation using existing vessel cameras, the solution strengthens cargo safety, enhances operational reliability, and contributes to the sustainability of global maritime transport.

Formal Specification of COLREG Steering and Sailing Rules

Westphal Bernd¹, Austel Anna¹, Wetzig Nina¹,

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Abstract:

For Maritime Autonomous Surface Ships (MASS) to take over navigational tasks, they need to interact safely with their environment and other vessels, both autonomous and conventional. In particular, like all vessels, they need to adhere to traffic rules, prominently including the International Regulations for Preventing Collisions at Sea (COLREGs). These regulations consist of 5 parts, including besides more technical requirements on lights, shapes and sound signals a part on steering and sailing.

As the rules in this part were originally intended as instructions for human operators, it is informal and leaves room for interpretation and expert judgement. For instance, they explicitly refer to “good seamanship” in multiple instances.

For MASS this part of COLREG evolves from instructions to experts to system requirements. The open and informal description is not suitable for this purpose. It does not provide an objective criterion to distinguish correct from incorrect behaviour, e.g., for testing, certification or monitoring during operation.

A precise and formal specification of the rules is needed to enable objective evaluation and provide clear goals for the design of MASS. Specifically, a formalisation of the steering and sailing rules is needed, that takes into consideration all aspects of the original rules. It should further specify the rules in terms of requirements on the behaviour of a single vessel, so that each violation can be attributed to a specific vessel. The formalisation must ensure, at least for 2-vessel encounters, that as long as all involved vessels adhere to the specification, they will pass each other at a safe distance. Finally, it should not over-specify the rules in the sense that each violation of the specification should correspond traceably to a violation of some aspect of the original rule text.

While different parts of the COLREGs have been formalised before, to the best of our knowledge, none of the formalisations have all of these properties. Some are exclusively concerned with categorisation of different types of encounters and do not detail the corresponding requirements for vessel navigation and others simplify the rules as appropriate for their specific application purposes.

In this work we aim to provide a formal specification of the COLREG steering and sailing rules for vessel encounters as they apply to a motorised vessel not restricted in its manoeuvrability with the abovementioned properties.

Study on Emergency Collision Avoidance for Autonomous Ships

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¹Department of Systems Engineering and Naval Architecture, National Taiwan Ocean University, Taiwan (R.O.C.)

Abstract:

With the advancement of technology, and in order to reduce maritime accidents caused by human error in vessel operations, countries around the world have begun to focus on the research and development of technologies related to Maritime Autonomous Surface Ships (MASS). Among these, the collision avoidance problem for autonomous ships is the most critical. However, this topic has been extensively discussed in numerous papers. Therefore, this study specifically investigates a special collision avoidance scenario: emergency collision avoidance.

This research specifically adds an emergency collision avoidance function to an autonomous navigation system that has been under development for many years. This autonomous navigation system already possesses path navigation, collision avoidance, and free maneuvering capabilities. Specifically: the path navigation function guides the ship according to a pre-planned route; the collision avoidance function allows the ship to avoid other vessels at any time, with strategies including altering the course or reducing speed; and the free maneuvering function allows for autonomous control of the engine and rudder, either ahead or astern, to safely guide the vessel along the predetermined path or for collision avoidance.

To verify the feasibility of the developed emergency collision avoidance function, the autonomous navigation system is associated with a ship motion simulation system. A 22-meter long twin-screw yacht is selected for the tests. First, the existing collision avoidance function of the autonomous navigation system is tested, ranging from two-ship to multi-ship avoidance scenarios. Subsequently, multiple multi-ship emergency collision avoidance scenarios are designed to challenge the newly added emergency collision avoidance function. Based on the test results, the decision-making of the emergency collision avoidance function allows the own ship to safely perform an emergency collision avoidance with the target vessels.

PARALLEL SESSION 9: CARGO OPTIMISATION

The Pulse of Maritime AI: Recent Developments, Sector Implications, and Ongoing Research

Angeloudis Panagiotis¹

¹Imperial College London, UK

Abstract:

The lasting impact of AI in the maritime sector will not come from the models alone. It depends on the tooling, the orchestration, and the domain-specific engineering required to make AI reliable in safety-critical environments.

Building on the overview of AI developments in the maritime sector presented at SMRC 2025, this talk examines how the landscape has shifted over the last 12 months and where it is heading. Agentic AI workflows have reshaped development pipelines, giving rise to a growing ecosystem of software products that address regulatory compliance, voyage optimisation, and operational reporting. Maritime operations are governed by physical, regulatory, and operational logic that purely statistical models cannot fully capture, particularly in edge cases where the consequences of failure are highest. As the initial wave matures, this gap between data-driven methods and domain engineering presents both a challenge for industry and an opportunity for research that can credibly bridge the two.

We examine where this convergence can happen and where academic contributions can be most consequential. Two areas are of particular relevance. The first concerns surrogate modelling techniques that approximate vessel-level physics at reduced computational cost, opening the possibility of fleet-scale modelling and scenario analysis that has historically been impractical. The second concerns simulation frameworks in which heterogeneous maritime entities, including vessels, port infrastructure, and regulatory mechanisms, are modelled as autonomous agents with embedded operational logic and physics-informed behaviour, moving beyond the simplified scheduling models that have characterised much of the agent-based literature. When extended to ship-port interaction and multi-modal logistics chains, such frameworks offer a complementary perspective to monitoring-oriented digital twin platforms by enabling forward-looking analysis that allows diverse stakeholders to explore operational trade-offs under uncertainty.

We discuss how these approaches relate to fleet decarbonisation under evolving IMO regulatory targets, the coordination of autonomous and conventional vessels in mixed-

traffic environments, and the optimisation of port call sequences in congested maritime hubs. We close by identifying directions that may warrant closer collaboration between academia, industry, and regulatory bodies.

Automated Cargo Allocation for Maritime Tankers: Hybrid Optimization and ML for Efficiency and Safety

Tan Peng Hui¹, Zhang Guoping¹

¹Agency for Science, Technology and Research, Singapore

Abstract:

The maritime industry is increasingly pivoting toward digitalisation to eliminate human error and enhance marine asset performance. A critical component of fleet management is cargo optimisation, specifically for the complex domains of chemical and crude oil tankers. Current industry practices rely heavily on manual decision-making, where operators determine stowage based on experience and manually verify compliance using loadicators. This manual approach is prone to errors due to the complexity of stability requirements and offers no guarantee of optimal stowage plans, often resulting in sub-optimal asset utilisation.

This work presents an automated solution, the Auto Cargo Allocation (ACA) system, for generating cargo stowage plans and loading/discharging sequences. The proposed architecture integrates a Hybrid AI/Machine Learning module with rigorous Mathematical Modeling within a cohesive framework. The system utilises Machine Learning to generate initial stowage plans based on historical similarity, which are then refined by mathematical models acting as strict constraints.

The optimisation framework employs a multi-objective approach designed to maximise cargo load and empty tanks while minimising ullage. To ensure operational safety and compliance, the model strictly adheres to complex constraints including cargo handling specifications like commingling rules, cargo history, adjacent temperature requirements, and USCG regulations. It simultaneously accounts for port restrictions such as maximum permissible draft and air draft. Additionally, the system rigorously enforces vessel stability mandates by maintaining positive trim, strictly controlling list limits, and ensuring that shearing forces and bending moments remain within 100% of their safety limits. The architecture further includes an Infeasibility Analyser to detect issues and automatically suggest fixes. Specifically for Very Large Crude Carriers (VLCCs), the system incorporates a Simulator Module to validate operations with precise valve sequence control before execution.

The proposed system has achieved significant operational improvements. Research results indicate a reduction in planning time of up to 90% through automation and a 20% increase in cargo loaded through resource optimisation. Additionally, the number of required tanks was minimised by up to 15%. Beyond theoretical application, this

system demonstrates substantial industrial impact. It has been commercially deployed on a fleet of 80 chemical tankers and 25 VLCCs. Future developments will explore new use cases in maritime applications to further advance fleet digitalisation.

AI-Enabled Metocean Intelligence for Safe and Efficient Maritime Operations

He Ruoying¹

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Abstract:

Reliable metocean information is a critical input for safe vessel operations, port planning, and fuel-efficient shipping. This paper presents an AI-enabled metocean intelligence platform designed to integrate seamlessly with existing maritime operational systems. The approach combines high-resolution environmental data, physics-based models, and data-driven enhancements to deliver timely, operationally relevant forecasts tailored to vessel and port-specific needs.

The system is designed to support timely decision-making, including route planning, weather avoidance, and fuel optimisation, while respecting established operational thresholds and regulatory frameworks. Case examples demonstrate how integrated metocean intelligence can improve situational awareness, reduce operational disruptions, and support cost-effective maritime operations without increasing complexity for operators.

This work highlights a practical pathway for deploying advanced metocean capabilities within smart shipping, digital twin, and fleet management environments, contributing to safer, more efficient, and more sustainable maritime operations.

Programmable 5G Network for Enabling Smart Port Operation

Lee Gary¹

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Abstract:

Digitalisation and automation are key trends in maritime port operations as the industry is moving towards smarter and greener future. In order to realise fully automated systems where yard cranes, autonomous guided vehicles (AGVs), and connected vessels are working in tight coordination, reliable wireless connectivity is essential to facilitate closed-loop control orchestration. Traditionally, wireless network is viewed as just a simple bit-pipes providing best efforts connectivity, which is insufficient to support autonomous port operations. However, with recent move towards cloudified 5G and increasing trend towards network API, wireless network is transformed into intelligent and programmable platform, providing opportunities to the developers and end users to exercise control and interact with the network based on their use cases and needs. This work presents how this is introduced into autonomous systems, the benefits it can bring, and the important considerations as it pertains to orchestration and optimising this new degree of control.

We first outline where relevant network control, in the form of network API, resides in the architecture. Particularly, we introduce the notion of quality-on-demand (QoD), review recent proof-of-concepts on its use case, and show how it could potentially make a difference in port automation through some illustrative examples. We then extend and pose the problem statement when we start to scale to multiple systems and show that in the extreme case whereby all systems greedily request for QoD privileges, the gains can become diminishing. We then set up a centralised, global optimisation problem over time and space that motivates having coordinated ways to schedule systems calls for QoD privileges at different time that minimises collisions or flooding, hence leading to performance improvement. Our proposed scheduling approach is practical and lightweight. It aligns well with ongoing industrial transformation, network API exposure architectures, and current maritime digitalisation trends/needs. It demonstrates that open network APIs, paired with provable online control, provide a practical foundation for safe, efficient, and scalable smart-port operations.

Joint Arrival Scheduling and Fuel-efficient Control for Smart Ships with Multi-agent Reinforcement Learning

Yang Xun¹, Yan Ran^{1*}

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*Corresponding Author: Yan Ran

Abstract:

Maritime traffic in major hub ports faces increasing pressure to control fuel consumption and emissions while keeping arrival patterns stable under dense and irregular flows. In ports like Singapore, constraints on space, arrival intensity, and scheduling often lead to severe vessel congestion. This failure to optimise traffic flows increases fuel consumption and air pollution, damaging the port city's environment and public health. Smart ship technologies promise richer sensing and communication, but many current planning tools still rely on static routing or centralised optimisation with simplified fuel estimates. These tools often fall short when traffic changes quickly or when heterogeneous vessels interact in narrow channels. A decision model that can react to changing conditions, preserve safety, and manage the trade-off between arrival timing and fuel use is therefore needed.

This study proposes a cooperative multi-agent reinforcement learning framework for smart ship traffic management that directly targets the joint control of arrival time and fuel consumption. Each vessel is modelled as an autonomous decision maker that adjusts its entry timing and speed while sharing limited situational information with other vessels. The environment is represented by a high-fidelity simulator of port approach operations that reflects conditions typical of Singapore, including berth constraints, time-varying arrivals, and strict safety rules. At each decision point, a vessel receives a compact view of its own state and a shared summary of local congestion and berth conditions. These signals reflect the type of information exchange expected in future smart ship corridors and support coordination without full communication.

A data-driven fuel model plays a central role in this framework. Instead of assuming a fixed analytical speed–power curve, fuel consumption is predicted by a pre-trained regression model built from historical voyage records. This model maps speed, loading condition, traffic segment, and environmental factors to estimated fuel burn. During reinforcement learning, the frozen fuel model provides a realistic and consistent fuel signal at each step, allowing the learning process to account for the true cost of each decision. The reward function balances estimated fuel consumption, arrival regularity, and safety. In this way, policies trained in simulation can express clear trade-offs between service efficiency and environmental performance. Policy learning follows a centralised-training, decentralised-execution scheme based on multi-agent proximal policy

optimisation (MAPPO). A shared actor network maps local observations to control actions, which makes the method scalable to fleets of different sizes. A centralised critic observes the global state during training and guides the emergence of cooperative behaviour.

Experiments on synthetic port traffic derived from real arrival patterns show that the learned policy reduces fuel consumption while keeping delays and safety constraints under control. The policy adapts to changes in traffic density and environmental conditions without retraining. These results suggest that cooperative reinforcement learning, combined with data-driven fuel modelling, can support the development of smart ship operations for high-traffic hub ports such as Singapore, where coordinated and energy-aware arrival control is increasingly important.

PARALLEL SESSION 10: SMART SHIPS

Construction Of HiLS Environment and Issues Organisation Corresponding Toward Certification Acquisition of Collision Avoidance System of Autonomous Ship

Tanihara Keisuke¹, Kureta Rui¹, Nakamura Jun¹

¹Monohakobi Technology Institute Co., Ltd., Japan

Abstract:

This study developed an evaluation and validation environment for the safety verification of autonomous vessel avoidance systems, considering cost-effectiveness and reliability improvements in system development. The environment comprises a Hardware-in-the-Loop Simulation (HiLS) system and a scenario generation and evaluation system. Simulations using diverse scenarios based on guidelines from classification societies and government agencies were conducted across multiple avoidance systems, enabling comparison and assessment of avoidance performance and safety indicators. Simulation logs are stored in IEC61162-450 format, allowing for extensible analysis through the addition of evaluation metrics and re-calculation. However, real-time validation within the HiLS environment involving actual hardware was found to be time-consuming due to equipment constraints, making it challenging to balance scenario coverage and verification efficiency. Future efforts will focus on combining real-time validation with fast-time verification using Simulation in the Loop Simulation (SiLS) and automated scenario generation during simulation, aiming to improve efficiency while maintaining comprehensive coverage. These advancements are expected to support autonomous vessel certification, international standard compliance, and the realisation of a cost-effective validation environment during development.

CFD-Based Analysis of Ventilation Design and Explosion Risk for Electric Harbourcraft Battery Room

Chong Mei Yan¹, Ong Wen Qi¹, Kanagalingam Sivamoorthy¹, An Hui¹

¹Singapore Institute of Technology, Singapore

Abstract:

The rapid move towards maritime electrification increases reliance on battery rooms for propulsion and auxiliary power, but confined spaces introduce serious fire and explosion risks. During a thermal runaway event, battery cells can release hydrogen (H₂) as the main flammable gas, which may accumulate quickly without sufficient ventilation. This study uses computational fluid dynamics (CFD) simulations to evaluate how fan capacity, which is measured in air changes per hour (ACH), influences H₂ dispersion and explosion pressure in shipboard battery rooms. Six battery modules are modelled, with one experiencing a thermal runaway involving eight cells releasing gas at 12 m/s. Results indicate that explosion pressure decreases as fan capacity increases—from above 3.6 bar at 6–12 ACH to around 2.5 bar at 30 ACH—demonstrating the benefits of enhanced air exchange. However, exceeding this ventilation level can increase turbulence, promoting gas recirculation and leading to a renewed increase in explosion pressure. These findings demonstrate the usefulness of the CFD method in evaluating and improving battery-room ventilation design for safer marine electrification.

Spatiotemporal Patterns and Predictive Risk Analysis of Maritime Accidents in UK Waters

Tang Jizhou^{1,3}, Cao Yuhao², Majumdar Arnab¹, Gao Xiaowei^{1,4}, Prof. Cheng Tao^{1*}

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Abstract:

Maritime accidents in UK waters pose persistent safety risks, yet most prior studies have examined only a single dimension in isolation. This study integrates spatial, temporal, and severity analyses using the Marine Accident Investigation Branch (MAIB) database (2013–2021) to better understand accident patterns. We applied Kernel Density Estimation (KDE) and DBSCAN clustering to identify accident hotspots, and implemented a two-stage feature selection (mutual information + LASSO-penalised logistic regression) to determine key predictors of accident severity. Machine learning classifiers, including logistic regression and XGBoost, were trained to predict whether an incident would be severe, with a Balanced Random Forest used to address class imbalance in the training data.

The results show that accidents cluster around major ports and shipping corridors (notably the Humber Estuary and the Solent), indicating these busy areas as persistent hotspots for maritime incidents. However, incidents in these high-traffic regions were predominantly minor in severity, suggesting that robust navigation safety measures and lower speeds mitigate the worst outcomes in port approaches. In contrast, certain remote coastal areas experienced fewer accidents but a higher proportion of severe (very serious) cases, likely due to hazardous conditions and slower emergency response. The severity modeling identified incident type (e.g. collision, capsizing), vessel characteristics (especially large tonnage), and adverse operational conditions (night-time, fog) as the strongest risk factors for severe accidents. Among the predictive models, the Balanced Random Forest achieved the highest recall (~78%) and AUC (~0.88) for severe accidents, outperforming the baseline logistic and XGBoost models in detecting high-severity cases.

These findings provide a data-driven basis for improving maritime safety in the UK. Maritime authorities and port operators can use the identified hotspots and risk factors to prioritise interventions. For example, enhanced traffic management and monitoring are recommended in busy port areas to further reduce collision risks, while improved emergency preparedness and targeted safety training are warranted for remote high-risk zones. This integrated approach demonstrates how combining spatial hotspot analysis with predictive modeling can inform more effective safety policies and port-based risk intervention strategies.

Understanding Aerodynamic Forces and Wake Flows Around Container Stackings Through Scaled Experiments and CFD Validation

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³Maritime Engineering, University of Southampton, Boldrewood Campus, UK

Abstract:

Efficient and safe container handling in maritime ports is increasingly challenged by high wind loads, particularly in regions such as Singapore, where climate change is increasing the frequency of strong, turbulent wind conditions. Safely maximising limited container yard space as ports expand and automate requires a detailed understanding of the behaviour of container stacks and clusters subject to localised wind conditions.

This project aims to advance understanding of the aerodynamic forces and wake dynamics acting on container stacks through a synergistic approach combining scaled wind-tunnel experiments and computational fluid dynamics (CFD) simulations. By characterising the flow behaviour and validating predictive models, the study seeks to enhance the reliability of model-based risk assessment tools and improve operational safety in container terminals.

A series of controlled wind tunnel experiments has been conducted at the University of Southampton Boundary Layer Wind Tunnel. Scaled-down models of container configurations at a model-to-full-scale ratio of 41 include a single container, a simple stack, and cluster arrangements. Tests are performed over a range of wind speeds from 20 to 40 m/s, reaching Reynolds numbers of 105, which are appropriate for simulating typical operational scenarios with fully developed turbulent flow. Force measurements on individual containers, together with flow visualisation and wind velocity data, are used to quantify aerodynamic loading and wake structures as a function of wind angle.

Complementary CFD simulations are conducted at the A*STAR Institute of High Performance Computing and validated against the experimental data, with particular attention to capturing unsteady wake interactions and pressure distributions. The validated CFD model will serve as a predictive tool for estimating aerodynamic forces across a range of container stacking geometries and environmental conditions. This combined experimental–numerical approach will improve confidence in CFD-based aerodynamic predictions, which are essential for operational decision-making and risk management in container ports.

Ultimately, the project addresses the critical challenge of accurately modelling aerodynamic forces in complex shipping port environments. The insights gained will help refine safety protocols and design standards for container-handling systems during

extreme wind events, thereby supporting more resilient port operations in Singapore and similar coastal urban regions.

Navigating in Waves and Currents: Challenges for Ship Manoeuvrability and Autonomy

Kudupudi Ravindra Babu¹

¹Technology Centre for Offshore and Marine, Singapore

Abstract:

Ship manoeuvrability in real operating conditions is strongly influenced by environmental disturbances such as waves and currents. These effects introduce complex, time-varying loads that significantly affect trajectory, stability, and control performance, posing important challenges for autonomous navigation systems. This study investigates the impact of waves and current effects on ship manoeuvring behaviour using a physics-based simulation framework that captures the interaction between hydrodynamic loads and vessel response. The formulation incorporates nonlinear manoeuvring forces derived from high-fidelity CFD simulations, enabling detailed representation of nonlinear hydrodynamic behaviour. Propulsion and resistance effects are included to represent realistic operating conditions. Simulation results demonstrate that environmental disturbances can lead to substantial trajectory deviations, increased turning radius, and degradation in path-following performance. In particular, steady currents induce persistent cross-track errors, while waves introduce oscillatory motions that affect heading stability and increase control effort. The implications of these effects on autonomous navigation are examined, highlighting the need for disturbance-aware control strategies to ensure accurate path tracking and safe operation. The findings emphasise the importance of incorporating environmental effects into manoeuvring analysis for next-generation maritime systems.

PARALLEL SESSION 11: CARGO OPTIMISATION

Information Asymmetry in FCFS Port Queues: A Game Theoretic Analysis of “Sail Fast, Then Wait”

Kitadai Ayato^{1*}, Yoshimura Shunta¹, Nakashima Takuya¹, Nishino Nariaki¹, Miratsu Rei², Mizutani Naoki³

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Abstract:

This study develops a novel queueing game model to explain a common practice in cargo shipping “Sail Fast, Then Wait” (SFTW), and demonstrates that resolving information asymmetry among ships can deconcentrate port arrival times. Historically rooted in nineteenth century sailing races and sustained today by First Come, First Served (FCFS) berth allocation, “utmost dispatch” charter clauses and demurrage incentives, SFTW leads operators to maximise speed to secure early priority even when this implies long idle times at anchor. This pattern is increasingly in tension with decarbonisation targets and coordinated arrival schemes such as BIMCO’s Just in Time Arrival Clause and the Blue Visby approach. We ask why SFTW emerges as a rational equilibrium response to FCFS competition under incomplete information and how improved information about vessels’ capabilities can unlock more energy efficient navigation without altering formal priority rules.

We formulate the navigating situation as a game in which vessels choose continuous arrival times to a congested FCFS port, subject to heterogeneous technological constraints that fix each ship’s earliest feasible arrival time. Preferences are minimal: all vessels strictly prefer earlier service completion and are indifferent to the split between sailing-waiting split, and queueing is fully endogenous with stochastic tie breaking. Under incomplete information, each vessel knows only its own earliest feasible arrival time and holds probabilistic beliefs about others. In this environment, the arrival game is a Bayesian timing game whose unique symmetric equilibrium is SFTW: every vessel sails as fast as technically possible and arrives at its earliest feasible time. Under complete information, the set of pure strategy equilibria expands. When feasibility constraints are common knowledge, there exist continuous intervals of best response arrival times preserving the same service order and completion time, so that “Green Navigation” with slower steaming becomes an equilibrium outcome without altering relative priority. Invoking Schelling’s notion of focal points, we argue that environmental norms and

decarbonisation pressures make the latest arrival in each interval the natural equilibrium selection.

To quantify this value, we calibrate the model using AIS data for 9,539 bulk carrier calls at Port Hedland, Australia. The port is approximated as a single server with effective service time $\gamma \approx 3.97$ hours inferred from berth acceptance intervals, and individual cargo handling times have a median of 36 hours. Ships experience a mean offshore waiting time of 100.73 hours (median 75), consistent with strong FCFS competition and SFTW. Interpreting observed arrival times as earliest feasible types, we use the complete information equilibrium to compute voyage specific “slack,” defined as a delay that can be introduced without changing service start time. The simulation yields an average slack of 1.54 hours per voyage and a total slack of 14,721 hours over the sample. Although modest relative to observed waiting at this highly congested port, this slack can be fully converted into slow steaming and fuel savings without any loss in operator utility. This shows that richer information on feasible arrival capabilities can reduce SFTW and unlock utility preserving emission reductions within the existing FCFS regime.

Characterising Vessel-Cable Interaction and Seabed Events Using Distributed Acoustic Sensing (DAS) for Maritime Safety Applications

Vuong Nhu Khue¹, Hu Dora Juan Juan^{1*}, Liu Wei¹, Zhang Hailiang¹, Dong Hui¹, Wang Yixin¹, Yue Meng Fai², Tan Bien Aik³

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Abstract:

Anomaly detection supports proactive maintenance of underwater infrastructure, mitigating downtime and operational interruptions. Given Singapore's status as a prominent global shipping hub, the integration of subsea cable sensing holds substantial promise in fortifying maritime safety and surveillance initiatives and safeguarding essential infrastructure.

This work presents recent progress under the Subsea Cable Sensing (SCS-DAS) programme in employing Distributed Acoustic Sensing (DAS) for vessel activity characterisation and subsea event detection. The study focuses on field validation of DAS signal behaviour during controlled vessel operations, including anchor drops on the seabed and injector movements during the subsea cable removal process, within the nearshore section of a sensing cable.

Anchor-drop experiments exhibited clear high-frequency components in the 25–35 Hz range during impact, consistent with mechanical excitation from anchor contact. During seabed trenching by deploying a high-pressure injector tool, distinct spectral features were observed:

- about 10 Hz associated with slow mechanical repositioning
- 30–36 Hz linked to the Hydraulic Power Unit (HPU)
- about 13 Hz corresponding to thruster blade-passing vibration

When the injector was mechanically coupled to the cable, the 13 Hz component propagated through the injector and umbilical, confirming a physical transmission path between the vessel and the subsea cable. When the linkage was released, this component disappeared, verifying that coupling occurs only under mechanical tension. Additional high-frequency signals (>25 Hz) recorded outside the test area suggest seabed-impact activity unrelated to ship operations.

By demonstrating that DAS can reliably detect and distinguish anchor, thruster, and hydraulic system signatures, this study highlights its potential as a non-intrusive, continuous surveillance tool for maritime safety. The capability for event classification and characterisation of seabed activities is critical for early detection of anchor-drag or unauthorised seabed interference near critical subsea infrastructure, supporting proactive cable protection and situational awareness for maritime authorities.

Current project utilises the dark fiber in the first span. Future research aims at expanding these capabilities over multiple repeaters and developing bright fibers with integrated communication and sensing functions will further push the boundaries of what is possible, leading to more resilient and informed management of our coastal and marine environments.

Sizing for Operational Excellence: A Simulation-Driven Study of Barge Scale in Inter-Terminal Transport for Next-Generation Port Efficiency

Liu Mengya¹

¹Centre of Excellence in Modelling & Simulation for Next Generation Ports, National University of Singapore, Singapore

Abstract:

As container ports evolve toward multi-terminal configurations with increasing functional integration, inter-terminal transport (ITT) operations have become essential for coordinating container flows across distributed yard and quay resources. The growing intensity of intra-port transfers — driven by transshipment, yard balancing, and operational flexibility requirements — places significant pressure on existing transport systems, particularly under constraints such as congestion, labour availability, land use limitations, and environmental considerations.

Waterborne barge transport has emerged as a promising alternative by leveraging underutilised maritime space within port areas. Compared to land-based transport, barging offers the potential for higher capacity movement with reduced reliance on scarce landside resources. However, the operational design of such systems — particularly the optimal sizing of barges for high-frequency, short-distance ITT — remains insufficiently understood. Prior studies have largely focused on isolated efficiency metrics or conceptual system designs, with limited attention to the dynamic interactions between barge size, service frequency, handling processes, and system-wide performance.

This study adopts a simulation-based approach, developing a model using the object-oriented discrete-event simulation (O2DES) framework to analyse the impact of barge capacity on ITT operations. The model captures key operational elements, including arrival patterns, resource allocation, and cargo handling processes. System performance is evaluated using metrics such as throughput, turnaround time, resource utilisation, and operational robustness.

The results highlight trade-offs in barge sizing decisions. Larger barges improve per-trip efficiency but may reduce service frequency and increase handling times, potentially leading to reduced responsiveness. In contrast, smaller barges enable greater operational flexibility and higher service frequency, but may introduce additional operational complexity. The findings underscore the importance of balancing capacity and frequency in system design.

This study provides a system-level perspective on ITT design and contributes to the development of scalable, resilient, and sustainable intra-port transport solutions through informed barge sizing strategies.

Towards Next Generation Port Service Intelligence: Leveraging Generative AI and Reinforcement Learning for Cruise Vessel Berthing Plan Optimisation

Yin Xiao Feng¹, Wang Ke¹, Chieng Roland¹, Xiao Zhe¹, Zhang Wei¹, Lin Jason¹, Fu Xiuju¹
¹Institute of High Performance Computing, Agency for Science, Technology and Research, Singapore

Abstract:

One of the key operational responsibilities of a cruise terminal service provider is preparing berthing plans for incoming cruise vessels. This process is typically performed manually by planners through detailed inspections of vessel and berth schematics, which can be both time-consuming and tedious. Planners must consider numerous operational constraints, including vessel dimensions, the location of provision, baggage, and other shell doors, as well as openings for utilities such as water and sewage. The berthing plan is also subject to frequent last-minute changes due to the dynamic nature of vessel operations and shifting requirements. Managing the berthing plan generation and these adjustments demands close coordination across multiple teams, increasing resource strain and potentially affecting safety, terminal efficiency, and service quality.

To address these challenges, this study proposes an automated system for berthing plan generation and optimisation. The proposed framework comprises:

- 1) an optimised pipeline for vessel schematic extraction using Large Language Models (LLMs) to identify openings, shell doors, Length Overall (LOA), and other vessel particulars;
- 2) a rule-based engine for berthing plan generation and feasibility checking;
- 3) a reinforcement learning (RL) engine for plan optimisation; and
- 4) an LLM-based module for responding to vessel berthing queries and providing recommendations for last-minute adjustments.

The proposed system aims to significantly reduce the time and effort required for berthing plan preparation through automation and optimisation, while minimising user intervention. It enhances flexibility, explainability, and adaptability of berthing plan adjustments through an LLM-driven agent and provides an intuitive digital interface to streamline the overall berthing planning process.

RESEARCH POSTER OVERVIEW

Poster Session Dates/ Times

22nd April 2026

11.20am – 1.00pm

- Networking Lunch and Research Poster Showcase

23rd April 2026

11.45am – 12.30pm

- Research Poster Competition Pitching

3.35pm – 3.50pm

- Announcement of winners for the Research Poster Competition

Poster Topics:

Poster Theme	Title	Presenter
Smart Ships	Adaptive Oscillatory Foil Propulsion System inspired by Thresher Shark Kinematics	Tan Xue Lin
	AI-Enabled Predictive Maintenance for Marine Auxiliary Machinery: A Smart Ship Approach	Cdt. Rahman Azizur
	Automated Ship Hull Inspection	Prasetyo Marcel Bartholomeus
	Decision-Making for Collision Avoidance Using MMG-Based Non-linear Model Predictive Control in Busy Waterways	Dr. Liu Yangyang
	Design of a Scalable Architecture for Harbour Craft Digitalisation	Koh Tsy Harn
	From Fleet Supervision to Teledrive: Designing a Human-Centred Maritime ROC	PhD Candidate Gusev Alexey
	Interactive Deep Learning Network for Improving Vessel Traffic Flow Prediction in Intelligent Transportation Systems	Chen Yang
	Investigation of Bottom-Laid Optical Cables for Wave Detection Using Distributed Acoustic Sensing in a Controlled Basin	Dr. Zhang Hailiang

Poster Theme	Title	Presenter
Smart Ships	Multimodal Neural Network-Based Motion Prediction for Autonomous Ships	Yeo Jun Hao
	Towards a holistic risk-aware collision avoidance strategy for MASS in port waters	Dr. Chen Xi
Maritime Energy	Biogenic Carbon Accounting in Lifecycle Assessment	Chew Shee Jia
	Decarbonisation with green ammonia using SOFC for power generation (NH ₃ -SOFC)	Sheng Zonghao
	Economic Risk Assessment of Hydrogen-Enabled LNG Ships under Fuel and Carbon Price Uncertainty	Dr. Law Li Chin
	Ensuring Climate Integrity in Future Maritime Fuel Trade: Isotopic Fingerprinting of Low-Carbon Fuels and Methane Emissions	Cui Yuxi
	FMECA Analysis of Full Electric Harbour Craft	Qi Yifei
	From General Arrangement to Hydrodynamic Performance: An Integrated Early-Stage Design Approach for Electric Harbour Craft	Myo Myat Thandar
	Hydrogen Permeability for Maritime Applications	Lu Le Heng Laurence
	Integrated Co-Simulation of Electric Tug Power and Propulsion System	Boggarapu Yasho Bharat
	Investigation on Soot Formation in Hydrogen-Enriched Marine Gas Turbines via Rich-Quench-Lean Combustion	Dr. Tan Yong Ren
	Machine learning-based multi-parameter uncertainty analysis in life cycle assessment of alternative marine fuels for green shipping corridors	Liu Ren
Two-Phase Ammonia Flowmeter Calibration System for Smart Ships	Ye Shaochun	

Poster Theme	Title	Presenter
Maritime Energy	When Does Green Methanol Break Even? A Cost-Parity Model Under EU ETS	Chiang Tai Yi
Maritime Cybersecurity	Byzantine-Tolerant Formation Control in Maritime Buoy Swarms	Shrivastava Siddhant
	Confined Space Connectivity for Maritime Use-cases	Sangle Manisha Sudhakar
	Data-Driven Debriefing in Maritime Training: An Integrated After-Action Review Platform	Wong Kan Hon
	Securing Maritime NMEA 2000: AI-Assisted Semi-Markov Detection of Cyber-Attacks via PGN Analysis	Abbad Kamel
	Spatiotemporal GNSS Integrity Monitoring for Maritime Navigation Using LSTM-Based Conflict Scoring	Sankalp Chakravarthy Sreenath
Cargo Optimisation	A Big Data-Driven Network Construction Method for Analysing the Dynamic and Complex Global LNG Maritime Transportation System	Wu Weihuang
	Automation of Coning and Deconing of twistlocks in Port Operations using Hybrid Grippers	Thanigaivel Naresh Kumar
	Computer Vision Based Early Detection of Container Loss at Sea	Lall Vishakha
	From AIS Trajectories to Congestion Forecasts: A Graph-Based Deep Learning Framework for Container Terminals	Wang Wenyu
	Improving Forecast of Extreme Wind Events for Maritime Operations Using Global Forecast System (GFS) Data	Wang Qiang
	Quantum-enabled Informative Transport and Logistic Robustness for Productivity Expansion in Digital Maritime Intelligence	Nguyen Hoang Hai Tra

SMART SHIPS

Adaptive Oscillatory Foil Propulsion System inspired by Thresher Shark Kinematics

Tan Xue Lin¹

¹Agency for Science, Technology and Research, Institute of High Performance Computing, Singapore

Abstract:

The **Adaptive Oscillatory Foil Propulsion System** is a bio-inspired propulsion technology that emulates the tail mechanics of thresher sharks. By combining video-derived kinematic measurements with machine learning-driven design optimization, the system generates high-aspect-ratio oscillatory foils capable of lift-based thrust. Adjustable parameters, including oscillation frequency, amplitude, span, chord, and duty cycle, allow the propulsor to operate efficiently across low-to-moderate speeds. This approach offers a novel alternative to conventional rotary propellers, enhancing efficiency and ecological compatibility in marine applications.

AI-Enabled Predictive Maintenance for Marine Auxiliary Machinery: A Smart Ship Approach

Cdt. Rahman Azizur¹

¹Academy of Maritime Education and Training University, India

Abstract:

The maritime industry continues to rely heavily on Planned Maintenance Systems (PMS), which are schedule-driven and often disconnected from actual equipment condition. This results in premature overhauls, unplanned failures, and avoidable energy losses. This research examines the transition from conventional PMS to AI-driven Predictive Maintenance Systems (PdMS) for marine auxiliary machinery, positioning PdMS as a key enabler of smart ships.

The study analyses how real-time sensor data, condition monitoring, and machine learning models can predict equipment degradation, optimise maintenance intervals, and improve machinery availability. A comparative framework is developed to evaluate PMS and PdMS across reliability, energy efficiency, maintenance cost, and operational risk. Findings indicate that PdMS enables earlier fault detection, reduces unnecessary maintenance, and contributes to improved fuel efficiency and emission performance through optimised machinery operation.

The research highlights predictive maintenance as a practical and scalable pathway toward intelligent, energy-efficient, and resilient maritime operations, aligned with the objectives of digitalisation and sustainable shipping.

Automated Ship Hull Inspection

Prasetyo Marcel Bartholomeus¹

¹Singapore University of Technology or Design, Singapore

Abstract:

Automated ship hull inspection is critical for improving operational efficiency, safety, and maintenance planning in maritime operations. Traditional inspection methods rely on divers to manually capture images of submerged hull regions, posing significant safety risks, particularly in complex niche areas such as sea chest, propellers, and bow thrusters. This work proposes an integrated robotic and vision-based solution for automated hull assessment and inspection. A remotely operated vehicle (ROV) equipped with a sensor and onboard edge computing performs in-situ data collection. Captured data is processed in real time using AI modules to enable mapping, ego-location, and semi-autonomous navigation. The system generates both real-time 2D hull maps and offline 3D interactive map for before-and-after cleaning comparison. Additionally, an interactive interface provides quantitative assessment, including biofouling distribution, estimated growth area, cleaning time, and projected fuel efficiency improvements. The proposed approach enhances inspection consistency, reduces human risk, and enables data-driven maintenance decisions.

Decision-Making for Collision Avoidance Using MMG-Based Non-linear Model Predictive Control in Busy Waterways

Dr. Liu Yangyang¹

¹Technology Centre for Offshore and Marine, Singapore

Abstract:

Maritime autonomy is reshaping vessel operations by enhancing safety, efficiency, and decision-making while reducing reliance on human intervention in complex and high-risk environments. A key enabling technology for Autonomous Surface Vessels (ASVs) is Collision Detection and Collision Avoidance (CDCA), which allows vessels to perceive, predict, and respond to surrounding traffic in compliance with the International Regulations for Preventing Collisions at Sea (COLREGs). The Singapore Strait and Tuas Port present a particularly demanding operational environment, characterised by dense vessel traffic, narrow waterways, strong tidal currents, and strict regulatory constraints. This study proposes a situation-aware, COLREGs-compliant CDCA framework for large vessels. The framework integrates a 3-DOF MMG-based nonlinear model predictive controller implemented in CasADi with environmental disturbance compensation, explicit COLREGs handling for multi-ship encounters, and AIS-driven real-time risk assessment using TCPA, DCPA, and a dynamic collision risk index. Simulation results demonstrate safe, efficient, and regulation-compliant autonomous navigation in dense coastal waters.

Design of a Scalable Architecture for Harbour Craft Digitalisation

Koh Tsyr Harn¹

¹Nanyang Technology University - Maritime Energy and Sustainable Development Centre of Excellence, Singapore

Abstract:

This work presents a scalable and field-deployable digitalisation architecture for small- and mid-sized harbour craft to address fragmented systems and limited onboard infrastructure. The architecture unifies heterogeneous onboard data sources and analytics within a single shipboard digitalisation framework. It supports multi-fuel and multi-vessel operations, enabling continuous monitoring of energy efficiency, machinery condition, and emissions performance.

The architecture incorporates multi-protocol data gateways, vision-based instrument reading, secure shipboard communication, and reliable edge-to-cloud data

synchronisation for continuous monitoring. The system was validated across multiple harbour craft under real operating conditions, demonstrating stable performance, improved machinery visibility, and enhanced operator awareness during sea trials. The results demonstrate the feasibility of a portable, data-driven platform to support practical digitalisation without major vessel retrofitting.

From Fleet Supervision to Teledrive: Designing a Human-Centred Maritime ROC

PhD Candidate Gusev Alexey¹

¹Norwegian University of Science and Technology

Abstract:



As maritime autonomy advances, remote operation centres (ROCs) are becoming critical for supervising vessels and enabling safe human intervention when automation reaches its limits. This project builds on earlier work conducted with the NTNU Shore Control Lab and translates small-scale concept exploration into 1:1 prototyping and testing. Through human-centred design, we developed a full-scale ROC that supports situational awareness, smooth transitions between fleet supervision and manual takeover, and sustainable operator comfort. The project combines targeted desk research, field and lab observations, stakeholder interviews, iterative prototyping, and testing with researchers and experienced navigators. Findings from the preceding design phase indicate that operator experience depends on balancing immersion, collaboration, and cognitive focus, and that fleet control and teledrive may be best supported by distinct but connected workstations. The ROC prototype demonstrate technical feasibility, operational relevance, and commercial viability for future maritime applications at sea today.

Interactive Deep Learning Network for Improving Vessel Traffic Flow Prediction in Intelligent Transportation Systems

Chen Yang¹

¹School of Navigation, Wuhan University of Technology, China

Abstract:

"As global economic integration accelerates, international maritime transport continues to expand, resulting in rapidly increasing vessel traffic density in shipping lanes and port areas. This growth has made the management and prediction of Vessel Traffic Flow (VTF) increasingly challenging. Accurate VTF forecasting is essential for enabling port authorities and maritime regulators to implement effective traffic management strategies, ensure navigational safety, and improve operational efficiency. However, VTF derived from Automatic Identification System (AIS) data is inherently complex, highly volatile, and strongly correlated across adjacent waterways, making reliable prediction particularly difficult. Most existing studies treat each channel independently and often fail to account for the interactive effects of traffic flows among neighboring waterways. To address these limitations, this paper proposes a novel deep learning-based VTF prediction model capable of capturing cross-channel interactions. Specifically, dedicated Long Short-Term Memory (LSTM) units are assigned to individual waterways, and the temporal VTF of each channel is sequentially fed into its corresponding LSTM. To effectively model inter-channel dependencies, a pooling-based interaction mechanism is introduced to enable information exchange between the central channel and its neighboring channels. The resulting output vectors from all channels are subsequently concatenated into a unified feature matrix, which is processed by a fully connected layer to simultaneously generate future VTF predictions for all channels. Extensive experiments were conducted using historical AIS data from multi-channel waterways. Comparative analyses against several benchmark models—including Back Propagation Neural Network (BPNN), Wavelet Neural Network (WNN), Recurrent Neural Network (RNN), and Gated Recurrent Unit (GRU)—were performed across multiple channels and time intervals. The experimental results show that the proposed model consistently outperforms all comparative methods in terms of prediction accuracy and stability. It effectively captures complex spatiotemporal dependencies and inter-channel interactive effects, demonstrating strong robustness in multi-channel VTF forecasting and providing valuable support for intelligent maritime traffic management and decision-making.

Investigation of Bottom-Laid Optical Cables for Wave Detection Using Distributed Acoustic Sensing in a Controlled Basin

Dr. Zhang Hailiang¹

¹Energy Research Institute at Nanyang Technological University, Singapore

Abstract:

Distributed Acoustic Sensing (DAS) can convert seafloor optical cables into spatially dense and continuous sensing arrays for monitoring oceanic environments. In this study, we present the results from using DAS to investigate the responses of bottom-laid optical fiber cables to surface gravity waves and varying water depth in a large controlled wave basin. The motivation of this study was to evaluate the capability of DAS to detect wave-induced signals under shallow to deep water conditions, as well as its sensitivity to low-frequency variations associated with water depth changes. Experiments were conducted at three different water depths with varying wave heights, periods, and wavelengths. In addition, a water-depth-varying experiment (12 m to ~2.3m in 15 minutes) was conducted to observe DAS strain response. The experimental results demonstrate the potential of using DAS and existing subsea cables as large-scale distributed hydrodynamic sensors for monitoring ocean processes and environmental changes.

Multimodal Neural Network-Based Motion Prediction for Autonomous Ships

Yeo Jun Hao¹

¹Technology Centre for Offshore and Marine, Singapore

Abstract:

Autonomous and remotely operated vessels must perceive, predict, and respond to environmental disturbances without direct human intervention. Accurate motion prediction is therefore essential to provide anticipation for guidance, navigation, and control systems. This research develops machine learning-based vessel motion prediction models to enhance situational awareness and decision-making in dynamic maritime environments. Multimodal neural networks integrate radar imagery of the surrounding wave field with historical motion data, using sensor inputs that can be measured directly onboard vessels. Synthetic radar images are generated to replicate operational wave radar measurements, while numerical experimentation with a physical vessel model in TCOMS' wave basin provides physically grounded motion responses for model development and validation. The developed models accurately predict all six degrees-of-freedom motions up to 60 seconds ahead in irregular wave conditions. By

improving motion predictability, this work enables autonomous systems to proactively adjust control actions, enhancing safety, trajectory adherence, collision avoidance, and energy efficiency.

Towards a holistic risk-aware collision avoidance strategy for MASS in port waters

Dr. Chen Xi¹

¹Technology Centre for Offshore and Marine, Singapore

Abstract:

Risk awareness and assessment are critical to enhancing the autonomy and safety performance of MASS systems. This study proposes a holistic risk-aware collision avoidance strategy for MASS operating in port waters. Specifically, the proposed framework firstly employs systems theoretic process analysis (STPA) to systematically identify potential hazardous events, unsafe control actions, and risk influential factors from a control-system perspective. The outcomes of STPA are then incorporated into a Bayesian network (BN) to estimate the real-time risk level of the operating environment. A spatial-temporal risk map is further constructed to quantify and visualise the evolution of collision risk level, which is further incorporated into a collision avoidance algorithm based on MPC control, enabling the vessel to perform active risk-informed and COLREGs-compliant maneuvers in complex port scenarios. The proposed methodology is validated by high-fidelity virtual testing simulations of multiple encounter scenarios within the Singapore port area.

MARITIME ENERGY

Biogenic Carbon Accounting in Lifecycle Assessment

Chew Shee Jia¹

¹Energy Studies Institute, National University of Singapore, Singapore

Abstract:

Bio-based fuels are increasingly discussed as a pathway toward net-zero emissions in maritime transport, with lifecycle assessment (LCA) commonly used to evaluate their greenhouse gas (GHG) emissions. Within LCA, biogenic carbon can be treated differently from fossil carbon depending on the accounting approach adopted, which may influence how reported climate performance is interpreted. Motivated by the need to better understand these differences, this study examines how alternative biogenic carbon treatments affect the presentation and comparability of LCA results. Using a representative bio-based marine fuel pathway, the study applies several widely used biogenic carbon accounting treatments within a comparative LCA framework to examine their implications for reported lifecycle greenhouse gas intensity indicators. The analysis focuses on how methodological choices shape reported climate performance and its interpretation, rather than assessing the inherent climate performance of the fuel, with the aim of supporting transparent interpretation and informed use of LCA results in maritime decarbonisation strategies and policy discussions.

Decarbonisation with green ammonia using SOFC for power generation (NH₃-SOFC)

Dr. Shen Zonghao¹

¹Imperial Global Singapore, Singapore

Abstract:

Using green ammonia in the maritime sector is a game-changer in promoting sustainability and reducing emissions. With its high hydrogen content, efficient storage and transportation, and lower flammability than hydrogen, ammonia is emerging as a promising hydrogen carrier. In addition, it can be used as fuel for solid oxide fuel cells (SOFCs) and combustion engines, offering high energy efficiency and scalability.

The project aligns with the spirit of the Decarbonisation Grand Challenge. By developing SOFCs optimised for ammonia use, the project targets emissions reduction in the maritime industry, a challenging sector to decarbonise. Through novel materials and

designs, the research not only advances ammonia-based energy systems but also offers scalable solutions applicable across industries. This initiative drives the transition to a low-carbon future, aligning with broader decarbonisation efforts on regional and global scales.

Economic Risk Assessment of Hydrogen-Enabled LNG Ships under Fuel and Carbon Price Uncertainty

Dr. Law Li Chin¹

¹Cambridge Centre for Advanced Research and Education Ltd, Singapore

Abstract:

The maritime sector is undergoing rapid transformation due to tightening carbon regulations and the emergence of hydrogen-based propulsion technologies. Previous studies demonstrated the thermodynamic feasibility of onboard natural gas reforming with pre-combustion carbon capture (Pre-CCS) and showed that integrating this system with combined-cycle gas turbine (CCGT) architectures can improve the efficiency of onboard blue hydrogen production. In the hydrogen-enabled LNG-fuelled ship examined in this study, liquefied natural gas (LNG) is converted onboard into hydrogen through reforming with Pre-CCS, where CO₂ is separated as a by-product. The hydrogen-rich fuel is then used to power a CCGT propulsion system, enabling substantial emission reductions. A conventional marine gas oil (MGO) vessel is used as the reference ship for economic comparison. To evaluate financial viability under uncertainty, the study develops a stochastic techno-economic framework combining a ship financial model with Monte Carlo simulations of LNG, MGO, and EU ETS prices (2030–2050). Results show the hydrogen-enabled configuration can achieve lower lifecycle costs and improved resilience under fuel and carbon price volatility.

Ensuring Climate Integrity in Future Maritime Fuel Trade: Isotopic Fingerprinting of Low-Carbon Fuels and Methane Emissions

Cui Yuxi¹

¹Agency for Science, Technology and Research, National Metrology Centre, Singapore

Abstract:

The transition to low-carbon fuels is central to the future of maritime energy, with methane and methanol emerging as key candidates for global bunkering as shipping decarbonises. However, the climate benefits of these fuels depend critically on verified production pathways, trade integrity, and control of methane slip during handling and use. This study demonstrates the application of stable isotopic fingerprinting as a physical tool to support transparent low-carbon fuel deployment. Two atmospheric samples from distinct emission environments and three industrial methanol samples of different origins were analysed. Methanol $\delta^{13}\text{C}$ values ranged from -29‰ to -65‰ and δD values from -150‰ to $+350\text{‰}$, reflecting diverse synthesis routes relevant to future fuel supply chains. Atmospheric methane signatures were consistent with biogenic influence, illustrating the method's relevance for methane-slip attribution. These results highlight isotopic fingerprinting as a promising approach to underpin trustworthy maritime fuel bunkering, emissions accountability, and the sustainable scaling of next-generation marine energy systems.

FMECA Analysis of Full Electric Harbour Craft

Qi Yifei¹

¹Singapore Institute of Technology, Future Ship and System Design, Singapore

Abstract:

Ensuring the reliability of a full-electric harbour craft (eHC) is crucial for maintaining consistent performance and operational availability across various conditions. Any design flaws or operational failures can directly threaten passenger safety. This analysis conducts a risk assessment of the eHC using the Failure Modes, Effects, and Criticality Analysis (FMECA) approach. The assessment covers four main subsystems: propulsion, energy storage, charging, and power distribution. Within the propulsion system, key failure modes such as stator winding degradation, rotor demagnetisation, and bearing malfunctions were identified as critical. Other high-risk issues, including faults in the propulsion converter power module and DC-link capacitor failures, were also highlighted based on their risk priority number. Critical components were identified in the remaining subsystems as well. The FMECA process prioritises components by analysing their

likelihood of occurrence, severity, and overall criticality to enhance the craft's reliability, safety, and maintainability.

From General Arrangement to Hydrodynamic Performance: An Integrated Early-Stage Design Approach for Electric Harbour Craft

Myo Myat Thandar¹

¹Singapore Institute of Technology, Singapore

Abstract:

The design of battery-electric harbour craft is strongly influenced by hull hydrodynamics, general arrangement, and onboard battery integration. For a fixed battery capacity, multiple battery placement configurations can be explored, each affecting hull dimensions, displacement distribution, and hydrodynamic resistance. These configurations, therefore, directly impact hull design and should be considered early in the optimisation process. This paper presents a design-focused approach that integrates battery room-driven general arrangement with hydrodynamic optimisation during early-stage development. A representative battery-electric harbour craft is developed with a fixed battery capacity selected to meet operational requirements, while allowing flexibility in battery configuration during hull form development. Reynolds-Averaged Navier–Stokes (RANS) Computational Fluid Dynamics (CFD) simulations evaluate calm-water resistance and propulsive power across multiple hull configurations and speeds. An operational speed profile is introduced, weighting each speed by its probability of occurrence, enabling energy efficiency to be assessed with a representative weighted metric. Results show that variations in battery arrangement significantly affect hull characteristics, resistance, and energy efficiency, highlighting the importance of integrated hull form and battery room layout optimisation in early design.

Hydrogen Permeability for Maritime Applications

Lu Le Heng Laurence¹

¹Agency for Science, Technology and Research, National Metrology Centre, Singapore

Abstract:

Hydrogen (H₂) is expected to play an important role in Singapore's future energy mix in line with the nation's target of net-zero greenhouse gas emissions by 2050. While ammonia is being considered for large-scale maritime deployment, other applications such as port refuelling, fuel cells, and onboard power systems ultimately use gaseous H₂. A key challenge in implementing these systems is material compatibility with H₂ under different pressure conditions. Thermoplastics mitigate H₂ embrittlement faced by metals but suffer from poorer H₂ barrier properties, causing long-term leakage that may affect safety and efficiency. This study presents the development of a reliable H₂ Gas Permeation Measurement Platform (GPMP) to accurately evaluate the H₂ barrier properties of materials under controlled environments.

Integrated Co-Simulation of Electric Tug Power and Propulsion System

Boggarapu Yasho Bharat¹

¹Singapore Institute of Technology, Singapore

Abstract:

"Marine Electrification is taking place at a rapid pace, and guidelines set by MPA to transform domestic harbour crafts to either use net-zero fuel or convert to full electric by 2030 have driven an uptick in full-electric new builds, with future fuel-readiness.

This study presents an integrated co-simulation framework for the digital twin development of an electric tug's power and propulsion system. Dynamic models of the electric drivetrain components—including battery systems, converters, motors, and control strategies—are coupled with propeller and hydrodynamic models to capture transient interactions between torque demand, shaft speed, vessel acceleration/deceleration, and ship speed variations. The framework enables analysis of load-RPM coupling effects and voltage bus disturbances under realistic operational scenarios.

In addition, steady-state operational models are developed using Automatic Identification System (AIS) data from existing conventional tugs to evaluate mission profile suitability, charging scheduling strategies, and energy consumption characteristics. The combined

dynamic and steady-state simulations provide insights into battery state-of-charge (SOC) evolution, peak power demands, and system stability throughout typical harbour operations. The proposed co-simulation approach supports early-stage design optimisation, improves power system sizing accuracy, and enhances performance verification for next-generation electric tugs."

Investigation on Soot Formation in Hydrogen-Enriched Marine Gas Turbines via Rich-Quench-Lean Combustion

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Abstract:

The IMO's increasingly stringent decarbonisation targets are driving the maritime industry toward carbon-free propulsion systems. While hydrogen emerges as an attractive carbon-free fuel for marine gas turbines (GTs), infrastructure constraints require interim hydrogen/hydrocarbon blends. However, the hydrocarbon fraction generates soot, which is a critical concern for both engine efficiency and pollutant emission.

This study presents a Rich-Quench-Lean combustion strategy specifically designed for next-generation GTs. Using a swirl-stabilised bluff-body combustor that replicates modern turbine architectures, we investigate the combined effects of hydrogen enrichment and staged dilution on soot formation. Five ethylene/hydrogen fuel blends were investigated at constant carbon content. Advanced laser diagnostics (PAH-PLIF and soot-LII) revealed that hydrogen addition alters PAH precursor residence times and reduces soot volume fraction by up to one order of magnitude.

Staged dilution with hydrogen blending reduces soot while maintaining stable combustion. This dataset validates GT soot models, supporting the industry's transition to IMO-compliant sustainable propulsion.

Machine learning-based multi-parameter uncertainty analysis in life cycle assessment of alternative marine fuels for green shipping corridors

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Abstract:

While alternative marine fuels provide a promising way for reducing greenhouse gas (GHG) emissions, they may shift environmental burdens to the fuel production (well-to-tank, WTT) stage. Life cycle assessment (LCA) provides a systematic way to evaluate environmental impacts of entire fuel chain. However, uncertainties in input data values and technological choices compromise the reliability of LCA results.

This study takes the Singapore-Australia Green and Digital Shipping Corridor (SA-GDSC) as a case study and explores electrolytic liquefied hydrogen (e-LH₂) and electro-ammonia (e-NH₃) as alternative marine fuels.

We built a model that enables structured uncertainty propagation and provides an interpretable causal structure that clarifies how uncertainties in input parameters jointly influence the GHG emissions. Specifically, this study identifies key drivers whose uncertainties have the greatest influence on emission reduction performance. Moreover, we identify the minimum-emission scenario for each ship category for all combinations of variable states.

Two-Phase Ammonia Flowmeter Calibration System for Smart Ships

Dr. Ye Shaochun¹

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Abstract:

Ammonia is emerging as a key fuel for maritime decarbonisation. Ammonia Mass Flow Meters (MFMs) are critical for the accurate fuel quantity measurement essential to reliable NH₃ custody transfer, engine performance assessment, and regulatory compliance. However, their deployment is hindered by metrological challenges arising from the thermodynamic properties of NH₃, leading to pervasive presence of two-phase flow conditions. Conventional calibration facilities employing surrogate fluids cannot reproduce ammonia's unique fluid-structure interactions, resulting in significant errors. Addressing this gap, National Metrology Centre (NMC), A*STAR, has developed a high-

fidelity two-phase ammonia calibration system. Employing a thermodynamic methodology rather than mechanical mixing, the facility generates a wide range of Gas Volume Fractions with internationally recognised traceability anchored in the single-phase domain. This infrastructure moves the industry from theoretical derating to empirical validation, enabling the robust instrumentation required for the safety, efficiency, and regulatory compliance of next-generation smart ships.

When Does Green Methanol Break Even? A Cost-Parity Model Under EU ETS

Chiang Tai Yi¹

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Abstract:

Shipping's entry into the EU ETS turns carbon into a direct cash cost, forcing shipowners to compare EUA payments with the premium for green fuels. We estimate the breakeven carbon price for switching from VLSFO to green methanol using 2021–2025 Bloomberg fuel and EUA price data, with all fuel prices converted to VLSFO-equivalent energy terms (LHV basis). The results point to a clear gap: at today's EUA levels (~\$65–86/tCO₂), green methanol is still more expensive on a fuel-plus-ETS basis. Parity by 2026 requires either a premium of about 1.5× or an EUA level above ~\$216/tCO₂. At a 2.0× premium, parity shifts to late 2028.

MARITIME CYBERSECURITY

Byzantine-Tolerant Formation Control in Maritime Buoy Swarms

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Abstract:

Maritime security operations increasingly rely on autonomous buoy swarm formations for critical missions including surveillance, search and rescue, and environmental monitoring. These interconnected cyber-physical systems face sophisticated cyber attacks that can compromise mission effectiveness and pose significant risks to maritime safety. This paper presents a robust Byzantine fault-tolerant formation control algorithm for maritime buoy swarms that maintains operational functionality under cyber-physical attacks. Our approach achieves task coverage under GPS spoofing attacks, resilience under communication jamming, and formation stability during actuator hijacking attempts. The multi-dimensional trust scoring system scores each agent across behaviour, communication, and trust dimensions. This trust-weighted formation control provides realistic attack monitoring while maintaining system functionality and mission integrity. Scalability analysis demonstrates consistent performance from 10 to 30-agent swarms. The system maintains mission capability even under significant attack scenarios, providing a robust foundation for secure autonomous maritime operations.

Confined Space Connectivity for Maritime Use-cases

Sangle Manisha Sudhakar¹

¹Agency for Science, Technology and Research, Institute for Infocomm Research, Singapore

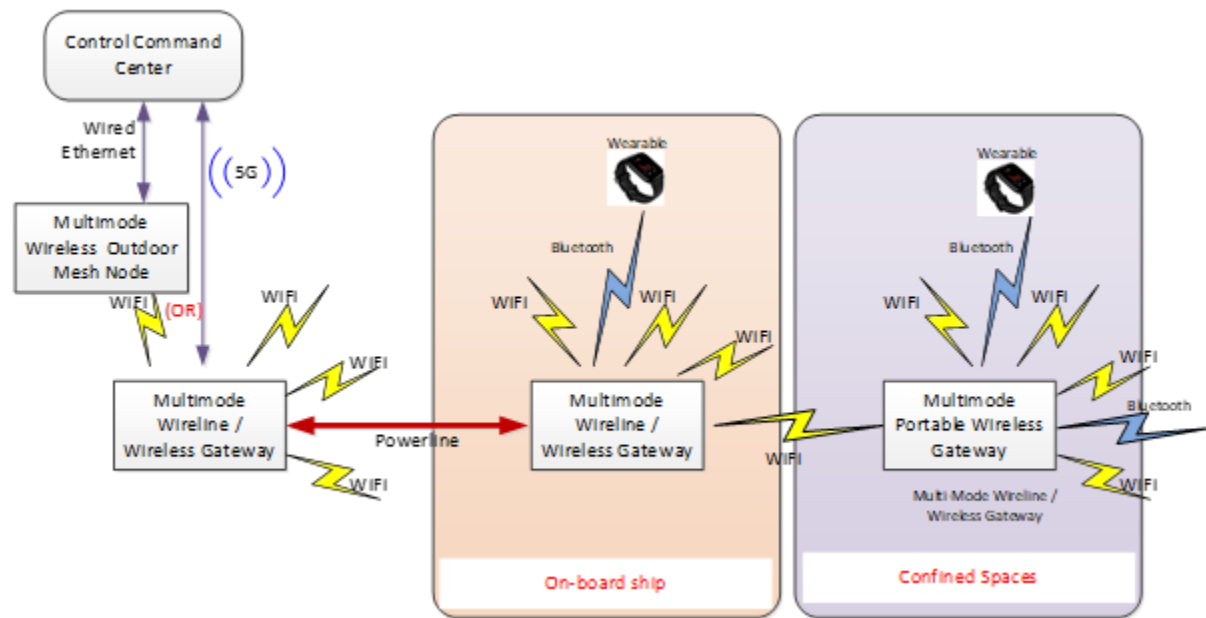
Abstract:

Providing reliable wireless connectivity in confined spaces is challenging due to physical and electromagnetic constraints. However, ensuring connectivity in such environments significantly improves worker safety, emergency response, and operational efficiency.

In marine sector, confined spaces are predominantly metallic, causing severe signal attenuation and multipath reflections that degrade wireless performance. Additionally, industrial activities such as welding and generator operation increase electromagnetic interference, further compromising communications reliability.

To address these challenges, a multimode network integrating WiFi (IEEE 802.11s), Bluetooth, and HomePlug AV has been developed. A multimode portable gateway extends network deeper into confined areas, enhancing scalability and robustness. The system achieves user data rates up to 30 Mbps in non-line-of-sight conditions over distances of 30 meters.

The solution has been deployed in a local yard. It supports real-time vital sign monitoring, worker localisation, and live video streaming, enabling remote expert assistance, improving productivity and reducing on-site technical presence. This has resulted in productivity improvements and emergency response times considerably.



Data-Driven Debriefing in Maritime Training: An Integrated After-Action Review Platform

Wong Kan Hon¹

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Abstract:

Maritime training generates extensive simulator and video data; however, the absence of an integrated review platform constrains instructors' ability to perform systematic and objective After-Action Review (AAR). This work presents an in-house developed AAR dashboard that consolidates simulator-derived performance analytics with multi-source media, including participant overview, eye-tracking playback with visual focus annotations, CCTV feeds, and instructor screen recordings to support structured, evidence-based debriefs of critical maritime emergency scenarios. The system automatically computes key navigational parameters, including vessel distance, heading-to-target/wind difference, final heading, and lateral speed, and flags both abnormal and within-normal behaviours to give instructors ready-to-use diagnostic insights. A key innovation of the platform is the linking of flagged performance events directly to synchronised data sources, enabling one-click access to critical moments and providing a comprehensive overview of human and operational performance. This facilitates targeted coaching of maritime trainees, thereby strengthening training outcomes and enhancing maritime safety.

Securing Maritime NMEA 2000: AI-Assisted Semi-Markov Detection of Cyber-Attacks via PGN Analysis

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Abstract:

This work secures maritime NMEA 2000 by detecting manipulated PGNs and bus-level flooding using an AI-assisted semi-Markov model. The approach combines adaptive risk binning learned from clean traffic with semi-Markov prediction (state transitions + sojourn times) to generate real-time alerts with a low footprint. Simulations across multiple scenarios achieve 98.5% accuracy, 99% detection rate, and 1.5% error rate.

Spatiotemporal GNSS Integrity Monitoring for Maritime Navigation Using LSTM-Based Conflict Scoring

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Abstract:

Merchant vessels operate GNSS-dependent (specifically GPS) bridge systems despite civil GNSS signals being unauthenticated and vulnerable to spoofing. Documented anomaly and maritime casualty analyses from the IMO highlight systemic risk amplified by human reliance on ECDIS overlays. Existing bridge systems verify signal availability but **lack behavioral integrity validation** as there is no option to check for discrepancy.

This research proposes a non-intrusive, software-only LSTM-based Co-Pilot for shipboard GNSS integrity monitoring. The framework passively collects the NMEA-0183 data (position, SOG, COG, heading, ROT, STW) and learns vessel specific spatiotemporal motion signatures using sliding-window (time based 30s) recurrent modelling. Adaptive multi-parameter **Conflict Score** quantifies residual divergence between predicted and observed kinematic states, enabling early prediction of gradual drag-off spoofing undetectable by rule-based logic.

Experimental validation for the software demonstrates 94.6% detection accuracy, 6.3% false-positive rate, and 17 sec mean detection delay, outperforming conventional threshold systems without hardware retrofit or automation override.

CARGO OPTIMISATION

A Big Data-Driven Network Construction Method for Analysing the Dynamic and Complex Global LNG Maritime Transportation System

Wu Weihuang¹

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Abstract:

The global liquefied natural gas (LNG) maritime transportation system is increasingly vital to energy supply chains, yet its network dynamics and disruption risks remain insufficiently quantified. This study proposes a big-data-driven method to construct a global LNG shipping network by integrating AIS data with complex network theory. We first process AIS trajectories of LNG carriers to identify voyages using multiple shipping-related features, providing the basis for network formation. Critical maritime passages are then incorporated according to geographic locations and other relevant characteristics. Edge weights are derived from large-scale AIS records to build a directed, weighted adjacency matrix capturing traffic direction and frequency, yielding an “export port–critical chokepoint–import port” topology. We analyse key topological properties and evaluate disruption scenarios, including port outages, single chokepoint failures, and compound interruptions. The proposed model enables vulnerability assessment in terms of connectivity, network efficiency, chokepoint criticality, and node substitution capability.

Automation of Coning and Deconing of twistlocks in Port Operations using Hybrid Grippers

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Abstract:

The project advances an autonomous mobile manipulation system for twist-lock coning and deconing, addressing a high-risk, labor-intensive operation at wharves. The developed Phase 1 platform, comprising a mobile base, dual collaborative robotic arms, a computer vision pipeline, and hybrid grippers, demonstrated over 160 successful autonomous operations across five twistlock types in PSA wharf trials, with average cycle times of ~80 seconds and robust performance in constrained, real-world conditions.

Phase 2 proposes improved speed, reliability, and broader compatibility with twistlocks through redesigned grippers and enhanced manipulation strategies. Hardware upgrades include added gripper dexterity, stronger multi-material lattice structures, and muscle-like actuators to increase holding stability. Embedded sensing and reinforcement learning-guided control policies will enable real-time detection of defects, jamming, and non-standard geometries.

These advancements support deployment readiness and align with PSA and SMI objectives for safer, faster, and fully automated wharfside operations(<40s).

Computer Vision Based Early Detection of Container Loss at Sea

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Abstract: "Containerised shipping underpins global trade, yet container loss at sea remains a persistent safety, environmental, and economic challenge. Despite compliance with Cargo Securing Manuals, dynamic maritime conditions such as vessel motion, wind loading, and severe sea states can progressively destabilise container stacks, leading to overboard losses. With new IMO mandatory reporting requirements for lost containers, there is an urgent need for reliable, evidence-based early detection solutions.

This study showcases a low-cost, retrofittable computer vision-based system for early detection of destabilised container using existing onboard cameras. The framework integrates computer vision deep learning segmentation to isolate container stacks, object tracking using optical flow and motion feature extraction to quantify relative movement, and temporal LSTM-based movement detection to distinguish normal vessel-induced oscillations from instability during varying visibility conditions.

By enabling early alerts for crew intervention and navigational adjustment, the proposed approach enhances cargo safety, operational resilience, and regulatory compliance."

From AIS Trajectories to Congestion Forecasts: A Graph-Based Deep Learning Framework for Container Terminals

Dr. Wang Wenyu¹

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Abstract:

Port congestion disrupts vessel schedules and reduces terminal productivity at major hubs such as Singapore, and can propagate to downstream ports in the shipping network, threatening global maritime supply chain reliability. Focusing on containerships, this study proposes an end-to-end framework that transforms AIS data into congestion prediction over global shipping network to support timely responses by port authorities. The framework starts by identifying terminal boundaries worldwide from vessel positions and constructs a directed graph representing terminal dependencies with hourly status features. Built on this representation, a novel graph-based neural network integrated with inverted transformer is developed to predict congestion for each terminal by encoding local temporal dynamics and capturing network-wide propagation. Despite the multi-step forecasting challenge from compounding uncertainty, our model achieves more stable performance than baselines and delivers reliable 72-step-ahead hourly forecasts, supporting anticipatory operational planning for container terminals and enabling identification of critical bottlenecks across the shipping network.

Improving Forecast of Extreme Wind Events for Maritime Operations Using Global Forecast System (GFS) Data

Dr. Wang Qiang¹

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Abstract:

Accurate forecasting of extreme wind speeds is critical for maritime safety, offshore operations and weather-resilient port planning. This study presents a binary classification-based forecasting model that integrates local observational measurements from the Meteorological Service Singapore (MSS) with global numerical weather guidance from the Global Forecast System (GFS). The model is trained and evaluated using a long-term dataset covering January 2017 to December 2024. To ensure the model's relevance to practical maritime decision-making, its performance was assessed across three operationally critical wind speed thresholds: 16 m/s, 12 m/s, and 10

m/s. Compared with observation-only models, the Critical Success Index (CSI) increases by 45–84%, with the largest gain at 12 m/s. The resulting CSI values—0.111 (16 m/s), 0.124 (12 m/s), and 0.178 (10 m/s)—are comparable to those reported in previous wind forecasting studies. The model remains computationally efficient and suitable for real-time maritime early-warning systems.

Quantum-enabled Informative Transport and Logistic Robustness for Productivity Expansion in Digital Maritime Intelligence

Dr. Nguyen Hoang Hai Tra¹

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Abstract:

Modern maritime transportation and port operations face escalating complexity due to time-varying demand, seasonal fluctuations, stochastic vessel arrivals, and unpredictable disruptions that contribute to congestion and inefficient berth coordination. To harmonise supply-demand chain balance, the research proposes a quantum-inspired intelligent maritime digitalisation integrating real-time predictability, probabilistic optimisation, and autonomous operational control. The framework incorporates historical data refinement, adaptive feature importance analysis, and climate-driven decomposition to extract time variant and residual behavioural patterns. A virtual probability tracking system integrates AIS/GPS, and sensor networks to monitor vessel routes including distance, speed, cargo volume, and goods quantities, while assessing uncertainty during long voyages. Quantum-inspired probabilistic optimisation enables the exploration of scheduling and berth allocation scenarios, potentially achieving 20% improvement in berth utilisation and 18% reduction in congestion. Integrated operational coordination, latency-aware routing, and predictive risk monitoring further 15% energy savings and 20% reduction in operational disruptions, supporting scalable and resilient smart port.

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