Understanding and Managing Risks in the Transition Towards Future Port Operations

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TCOMS

Singapore: A Global Maritime Hub

3.11 billion

Gross Tonnage

Annual vessel arrival tonnage in Singapore port grows by 0.6%, reaching a new record of 3.11 billion.

622.67 mil

Cargo throughput

Cargo throughput handled at Singapore port increases by 5.2%, reaching 622.67 million tonnes.

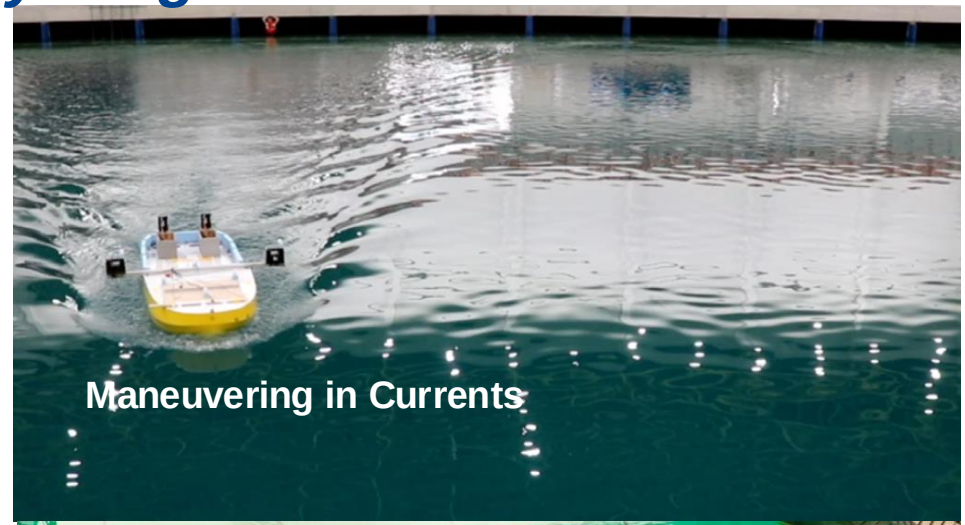
54.92 mil

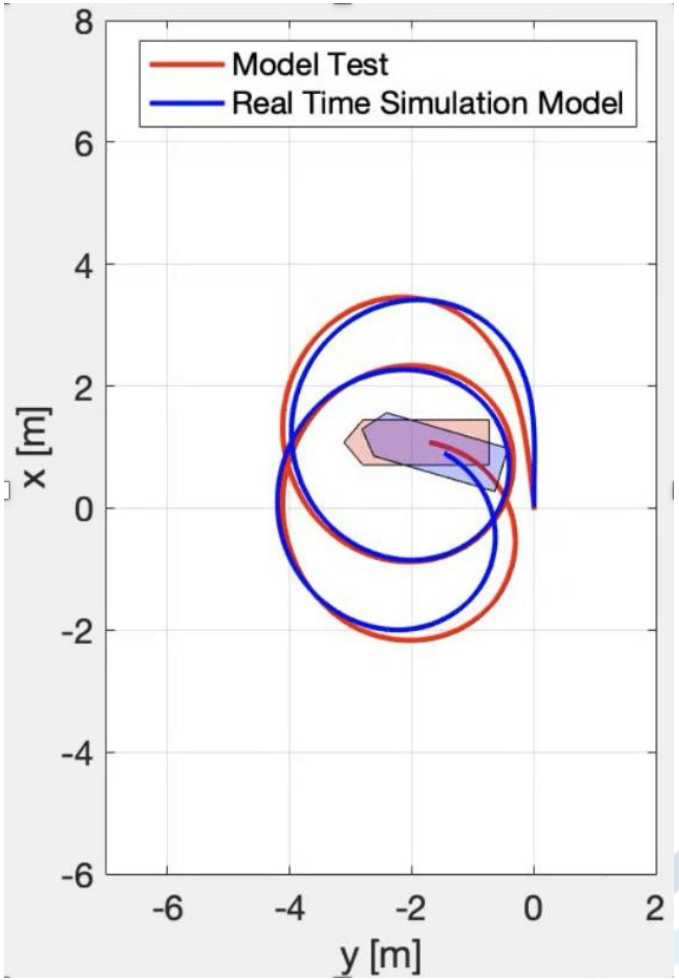
Fuel bunkering

Marine fuel sales hit a record 54.92 million metric tons in 2024, 6% from 2023. Trials of ammonia and methanol.

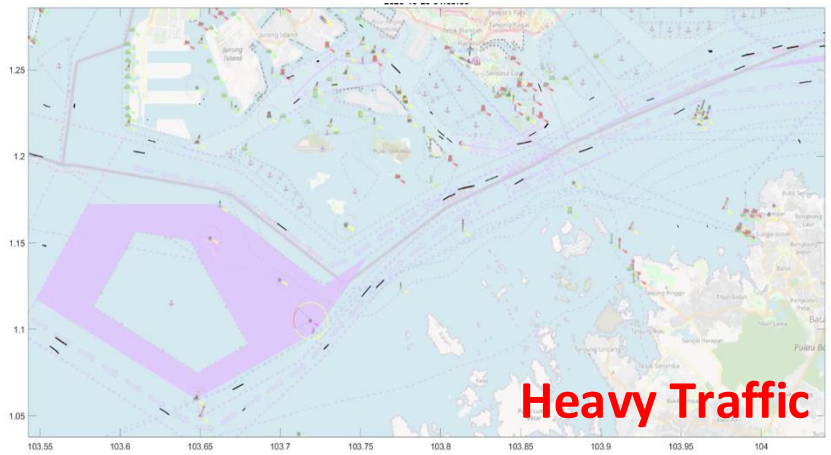
Data source: MPA media release, Strong growth momentum for Maritime Singapore (15 January 2025)

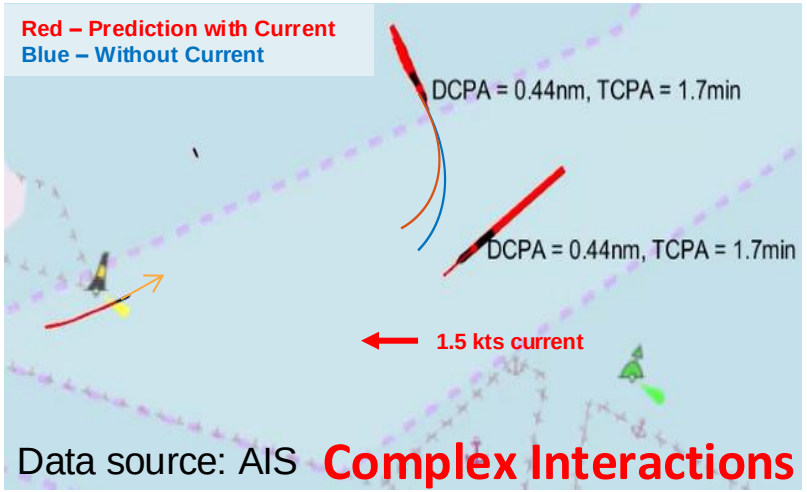
Developing Autonomous and Remotely Controlled Tugs - *Early Stages*

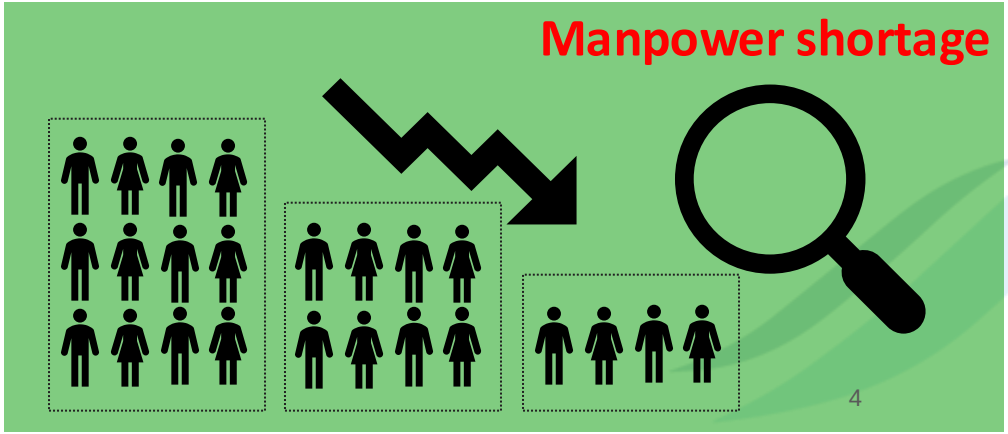




Key Challenges in Scaling Up
- *Complex Vessel Movements and Interactions*



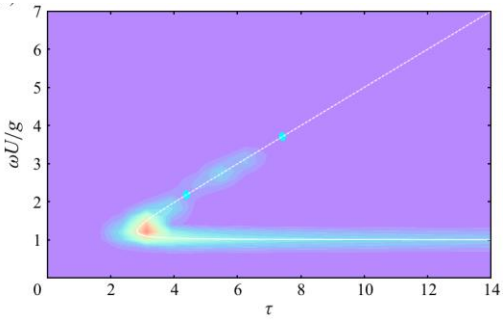




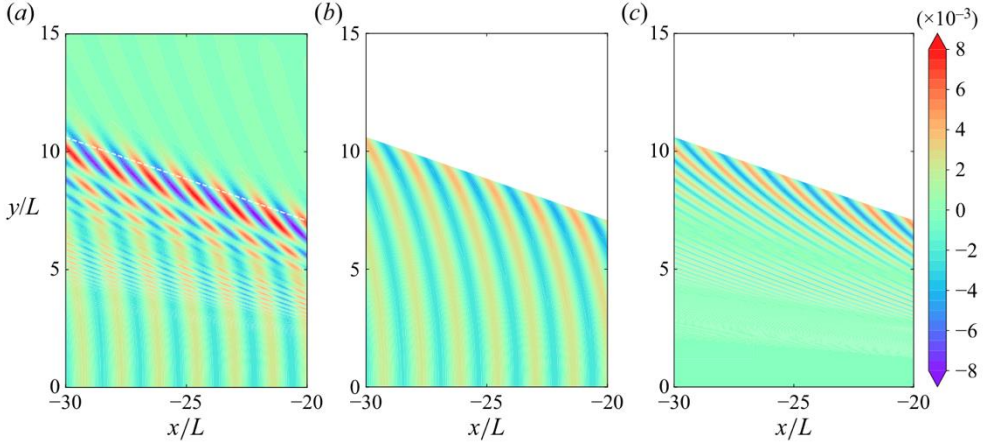
Operational Requirements and Risks That Need to be Addressed

- **Assurance** of autonomous or remotely controlled operations
- Addressing evolving **behaviours and responses** of vessels ranging from autonomously controlled to manned and remotely controlled vessels at the system level
- Addressing **changes in the operating environment** (winds, waves & currents)
- **Need for standards** in context of a complex and busy port environment
- **Mitigations** and **management of residual risks**

An effort that would require collaborations

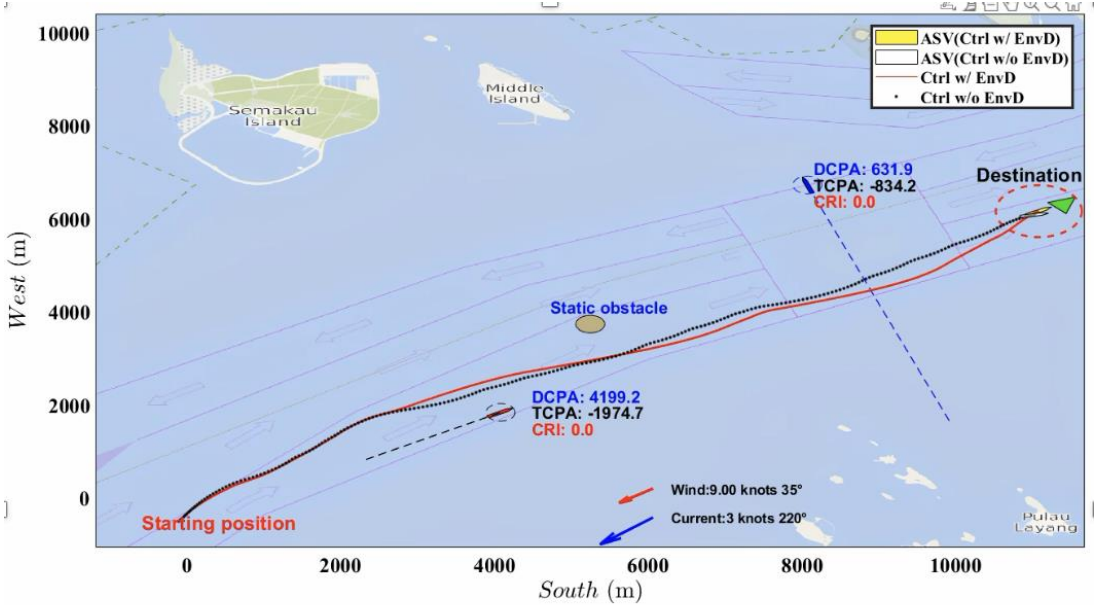


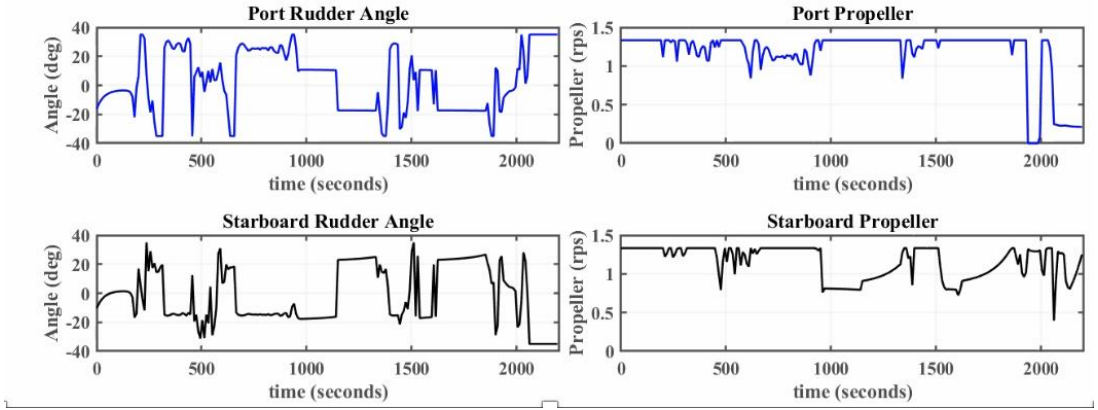
Ship Generated Waves

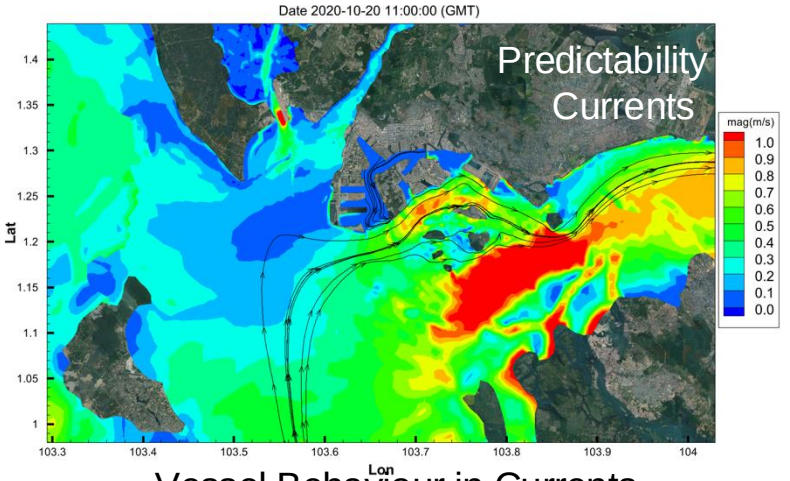


Liang, H., Li, Y., & Chen, X. (2024). An Earth-fixed observer to ship waves. Journal of Fluid Mechanics, 984, A14.

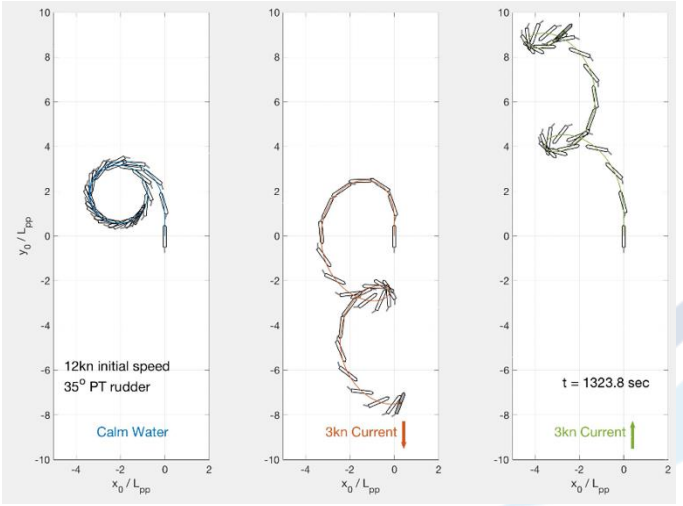
Enhanced Control Considering Environmental Disturbances



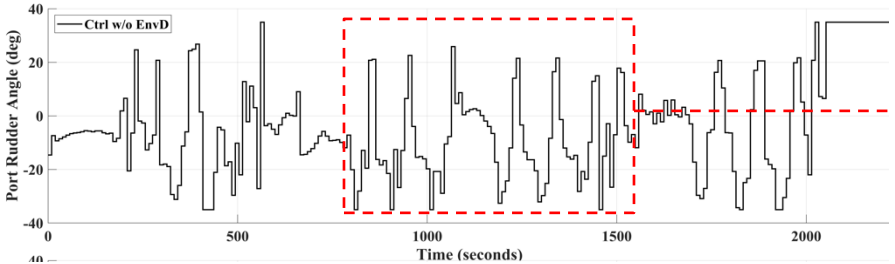




Vessel Behaviour in Currents

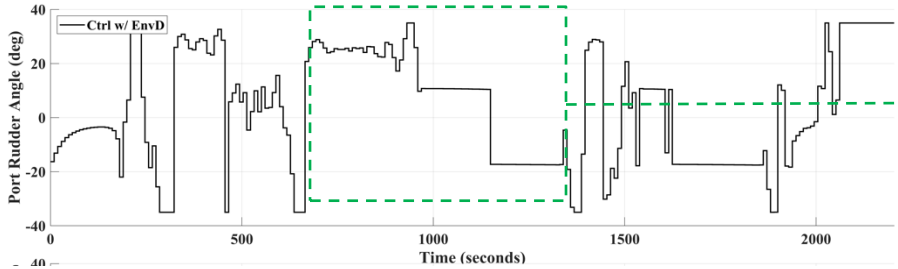


Difference in Control With and Without Consideration of The Currents



Controller unaware of environmental disturbance

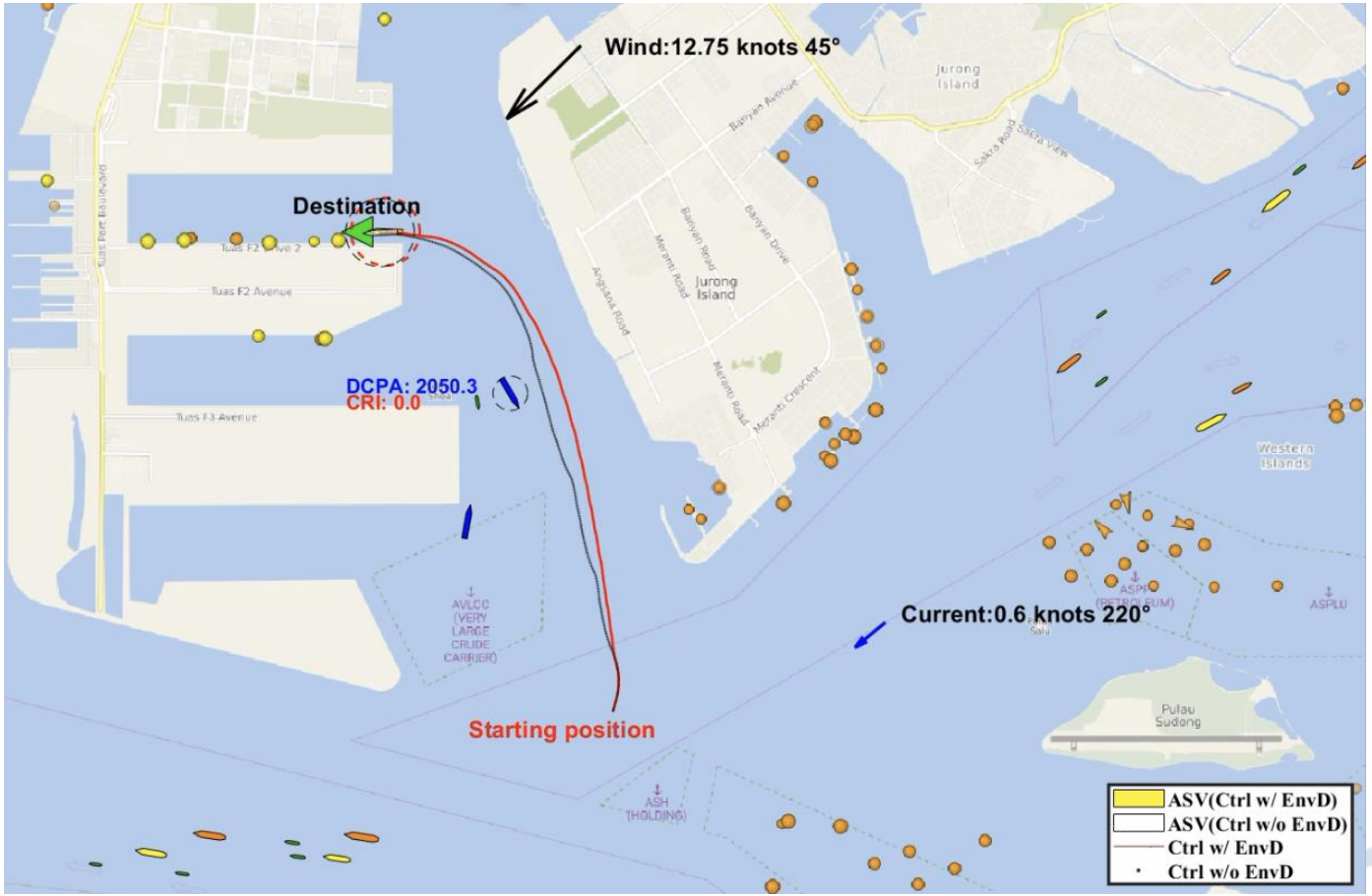
Requires frequent changes in rudder angle to maintain steady course in the presence of currents



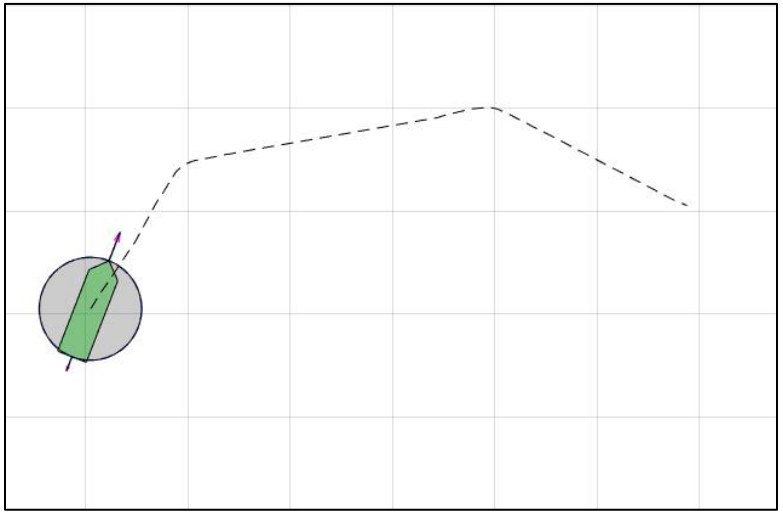
Environmental disturbance-aware controller

Changes in rudder angle are more stable as the effect of environment is taken into consideration

Environmental Disturbance-aware Controllers Demonstrate Superior Responses in Complex Scenarios



Autonomous Tugging and Berthing for Large Container Ships



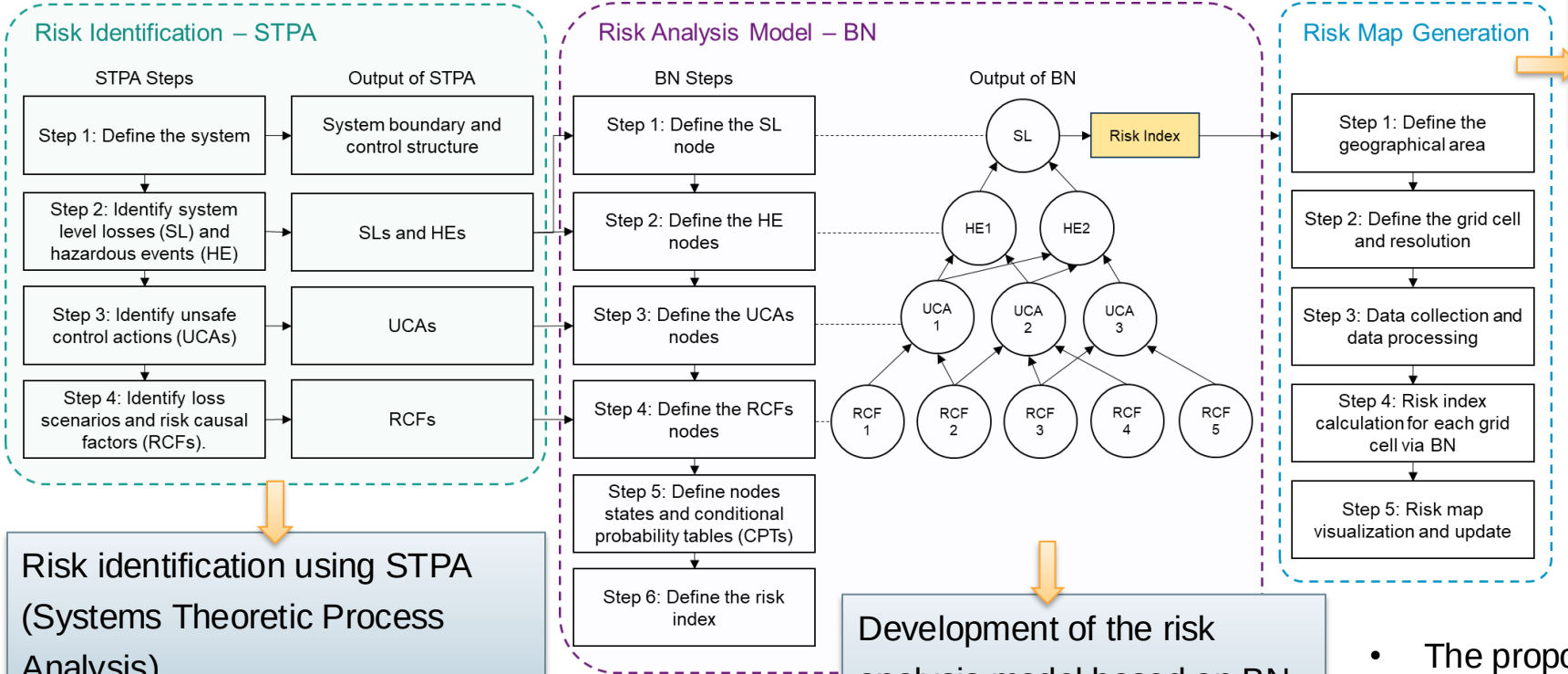
Successfully developed an algorithm for towing and berthing a vessel using two autonomous tugs

Quantifying Risk Associated with Autonomous Vessel Operations

Risk = *f* (*Encounter scenarios* ⇧ | *Operating constraints* ⇧ | *Environmental factors* ⇧ | *Vessel behaviours* ⇧ | *Control logic* ⇧ **)**

Encounter scenarios	Operating constraints	Environmental factors	Vessel behaviours	Control logic
-Traffic pattern	-Waterway restrictions	-Wind, waves and currents	-Hull shape	-Path planning
-Time and distance to closest point of approach	-Size of vessels	-Visibility	-Propulsion	-Collision detection
	-Speed control		-Human-machine interaction	-Collision avoidance
				-COLREG compliance
				-Risk evaluation

Systematic Framework for Risk Analysis



Risk identification using STPA (Systems Theoretic Process Analysis).

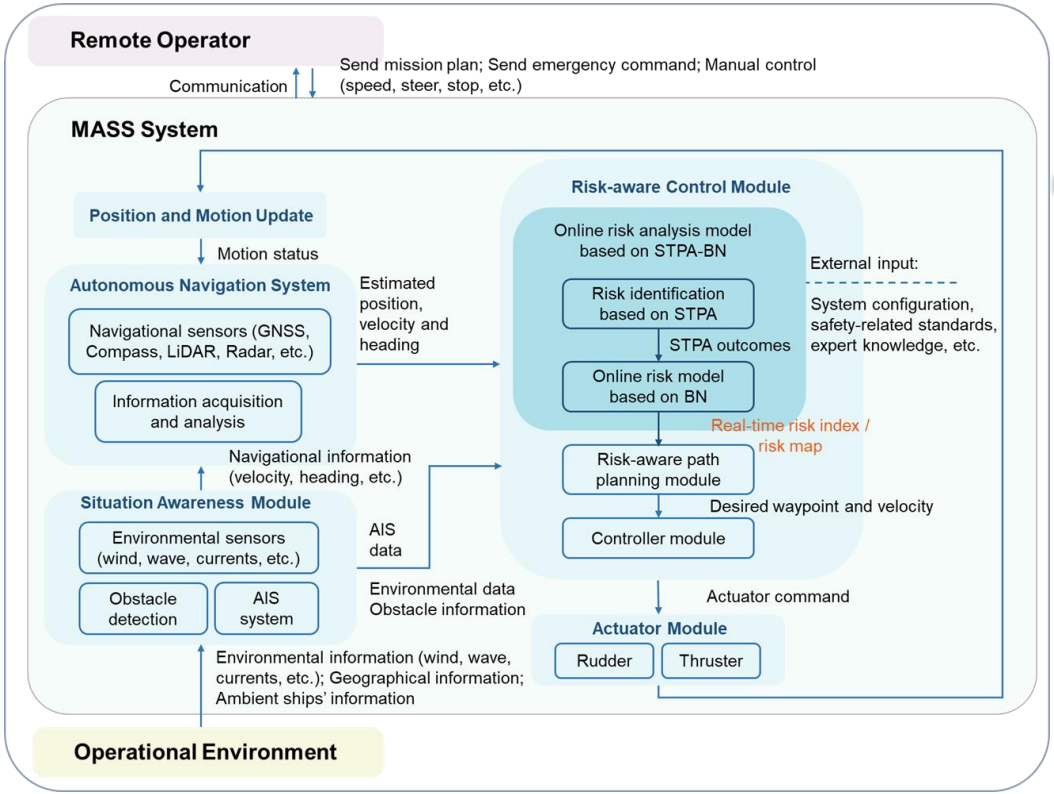
Development of the risk analysis model based on BN (Bayesian Network)

Risk index and spatial-temporal risk map generation.

- The proposed framework is tailored for the MASS system. It also can be adapted to other marine autonomous systems.

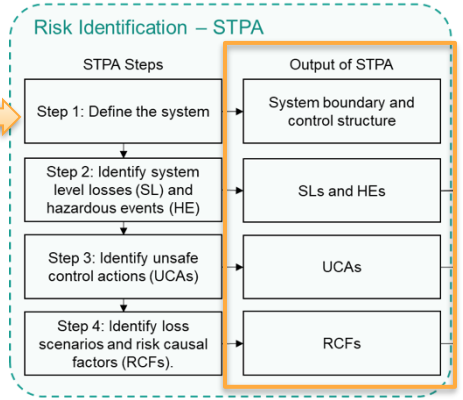
Chen X, Tan CE. (2025) Towards a systematic safety evaluation framework for MASS in congested port waters. The 44th International Conference on Ocean, Offshore, and Arctic Engineering, Accepted for publication.

Application of Risk Analysis Framework to MASS



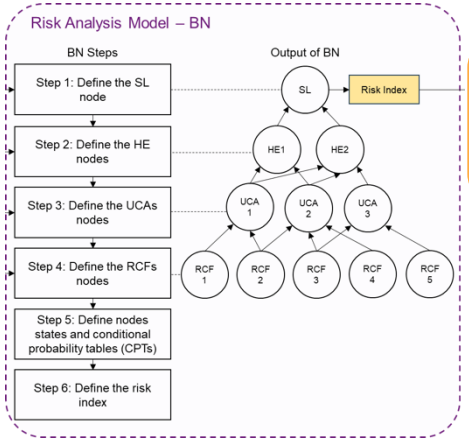
Hierarchical control structure of the MASS system.

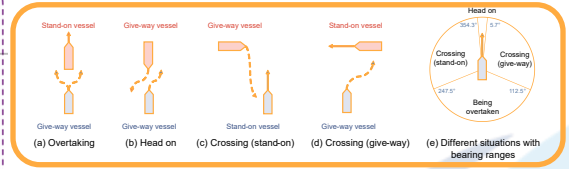
Risk Identification - STPA



Outputs of STPA, including hazardous events, unsafe control actions, and risk causal factors, are then mapped into the BN model.

Development of the risk analysis model based on BN





Meanwhile, consider **four encounter scenarios** of COLREGs.

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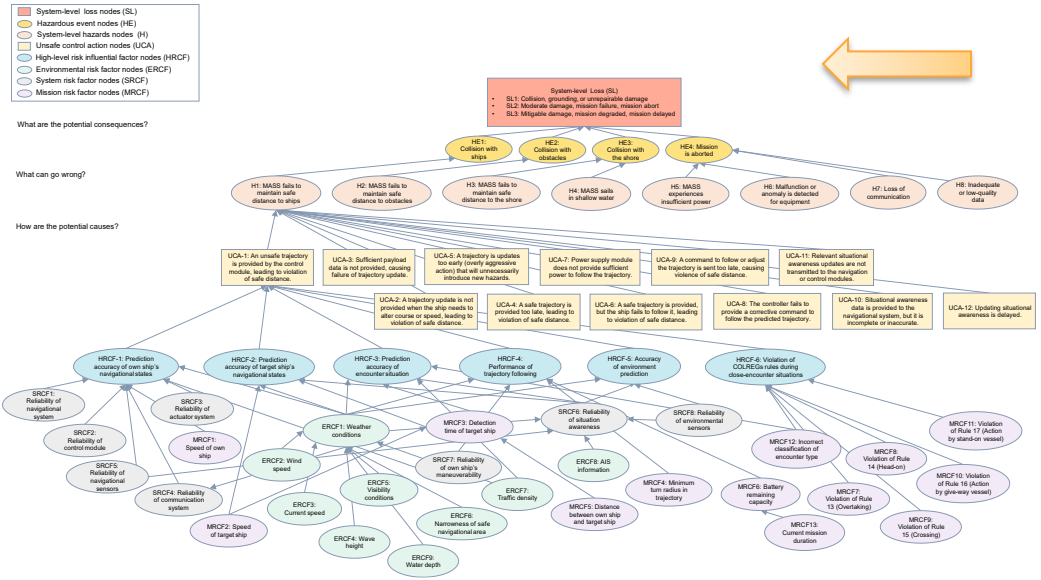
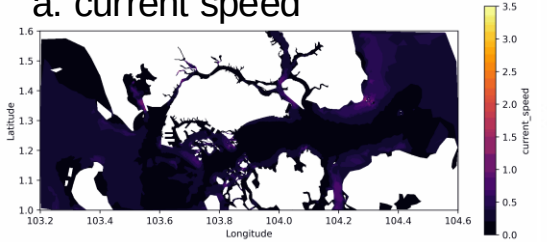
Risk Index Generation



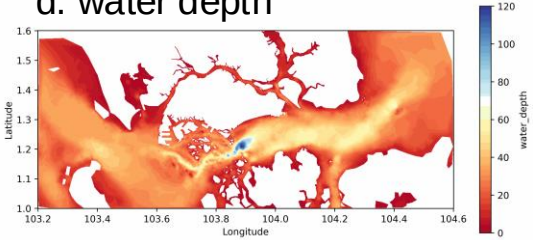
BN model development.

- **Input dataset** (currents, waves, AIS, etc.)

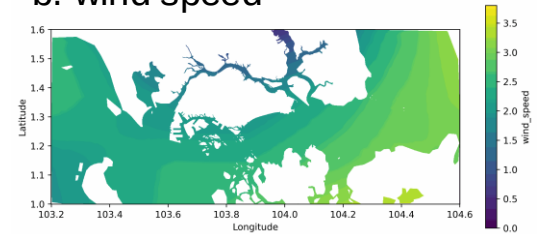
a. current speed



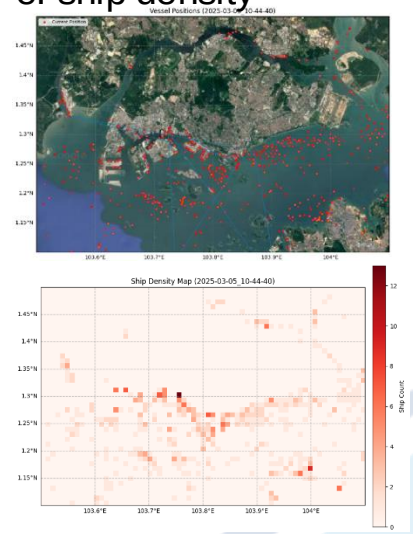
d. water depth



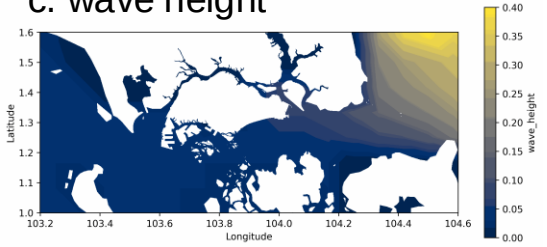
b. wind speed



e. ship density



c. wave height



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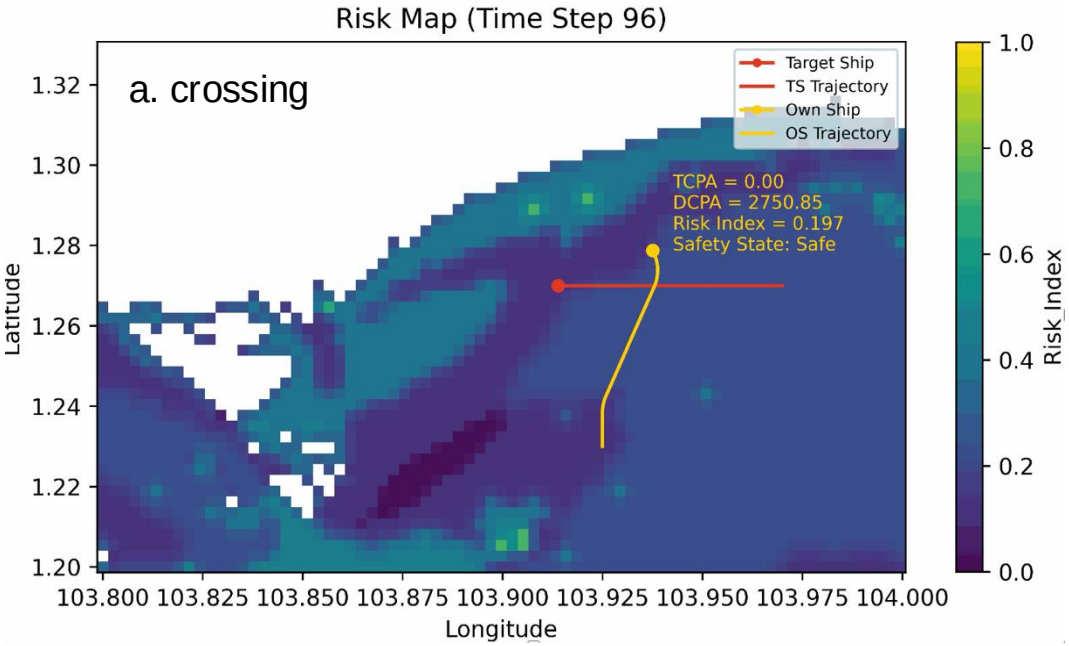
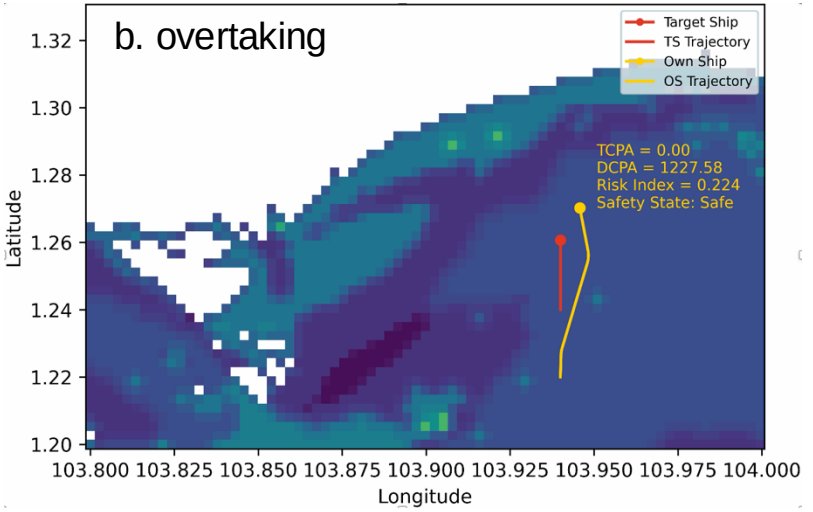
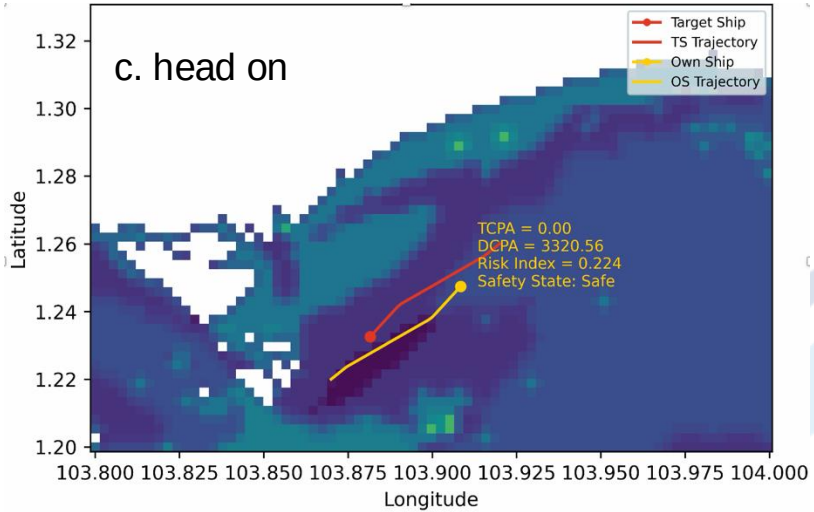
Ship Encounter Scenarios

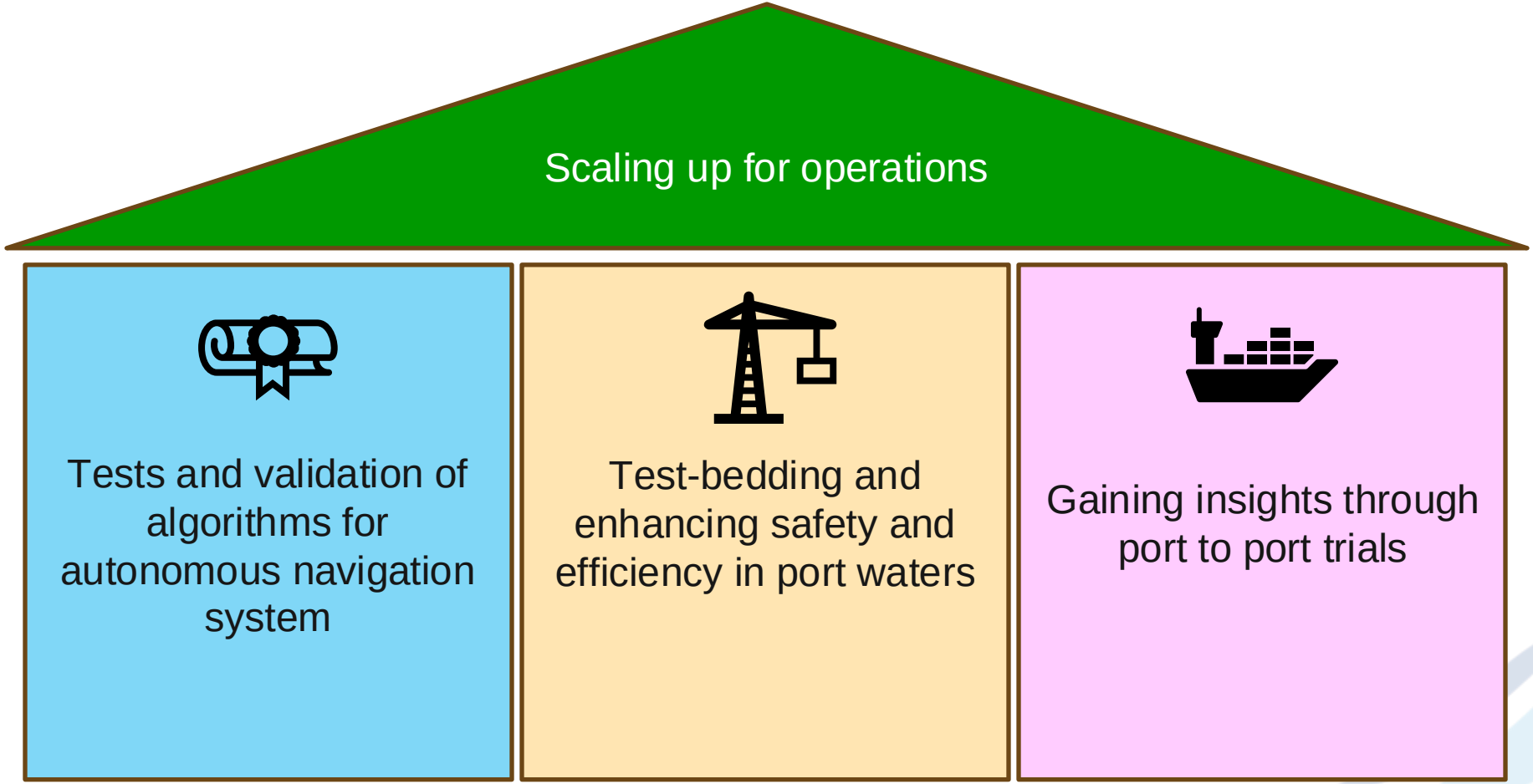


Collision warning at timesteps 17-24 & 49 (a premature course correction towards waypoint)



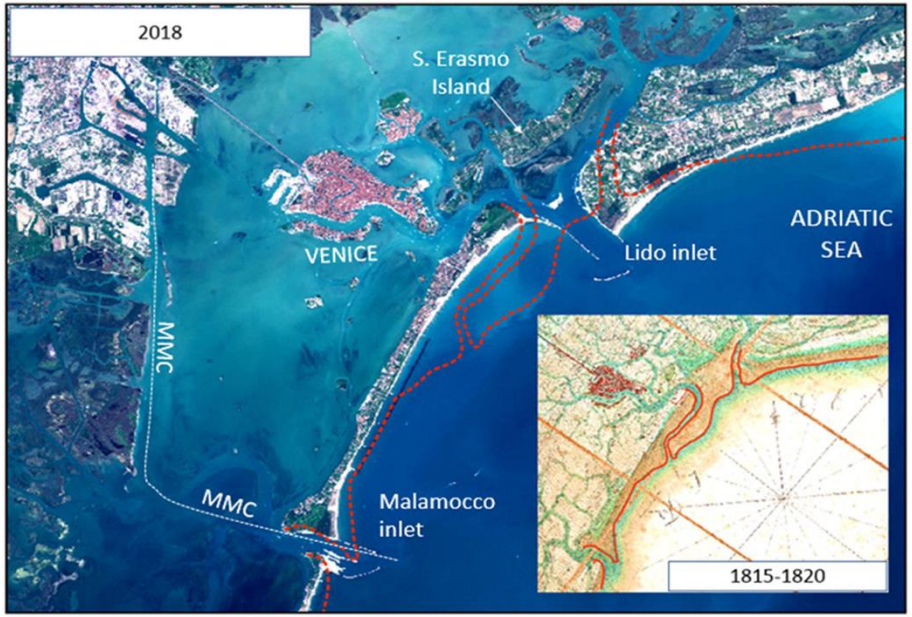


Next Phase


Scaling up for operations
Tests and validation of algorithms for autonomous navigation system
Test-bedding and enhancing safety and efficiency in port waters
Gaining insights through port to port trials

Ship Wakes: An Overlooked Hazard in Port Waters

Major environmental impact source in coastal waters (Scarpa et al., 2019)



Evidence of damages due to ship wakes (Pinkster & Keuning, 2013)

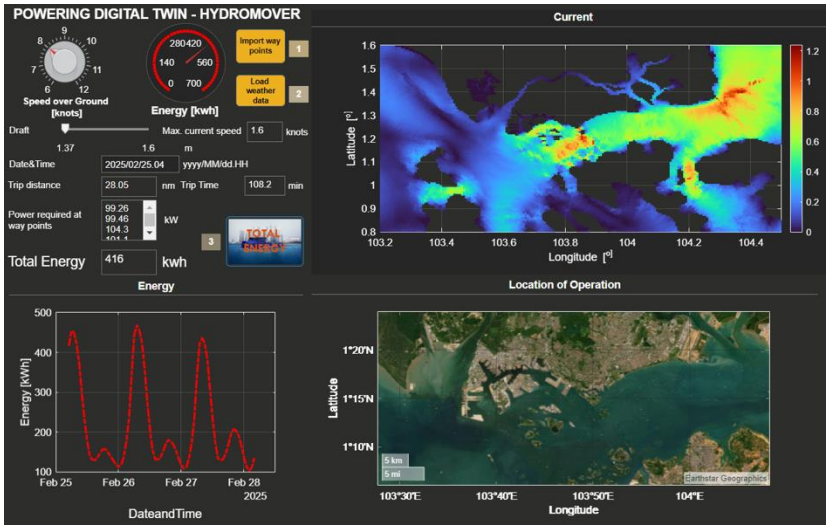
- 40% of mooring equipment damage in nearshore waters due to ship wakes (Netherlands Ministry of Transport and Waterways)
- Capsizing of small fishing boats due to the ship waves from a large passing ship (National Transportation Safety Board in the US)

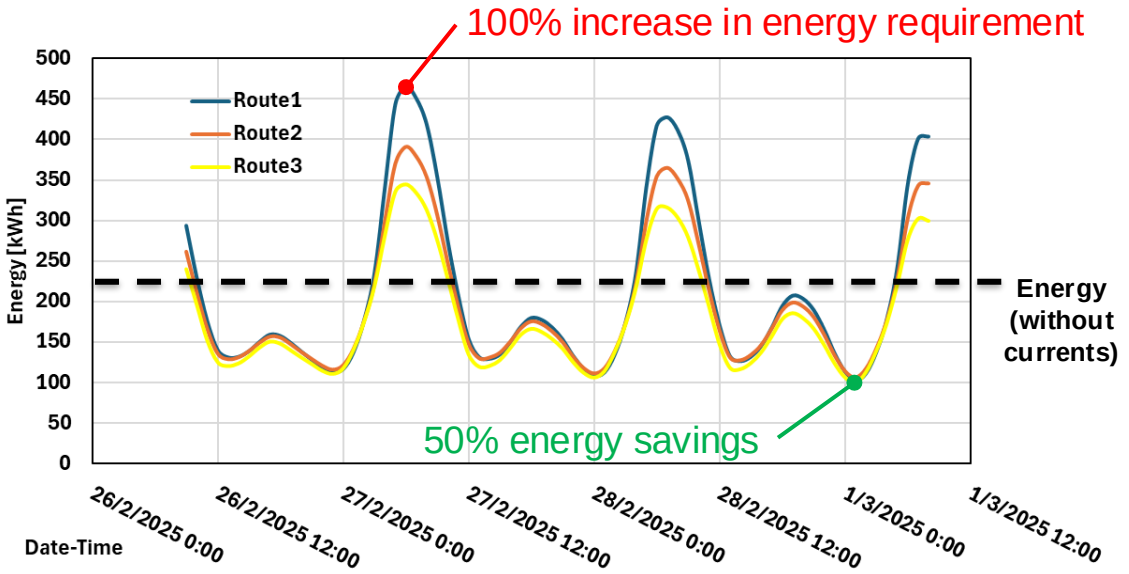
Pinkster, J. A., & Keuning, J. A. (2013). Prediction of the effects of fast passing vessels on moored vessels. In International Conference on Offshore Mechanics and Arctic Engineering, ASME.

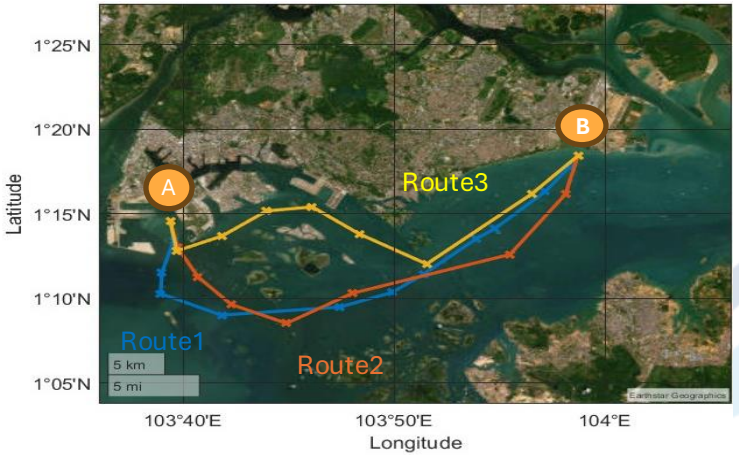
Scarpa, G. M., et al. (2019). The effects of ship wakes in the Venice Lagoon and implications for the sustainability of shipping in coastal waters. Scientific reports, 9(1), 19014.

Harnessing Knowledge for Smart Shipping

- Powering digital twin leveraging real-time forecast of wind, waves, and currents
- Energy requirement varies significantly over time and route due to changing speed and directions of currents







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Thank you