Weather Routing Based Multi-Energy Ship Microgrid Operation Under Diverse Uncertainties: A Risk-Averse Stochastic Approach

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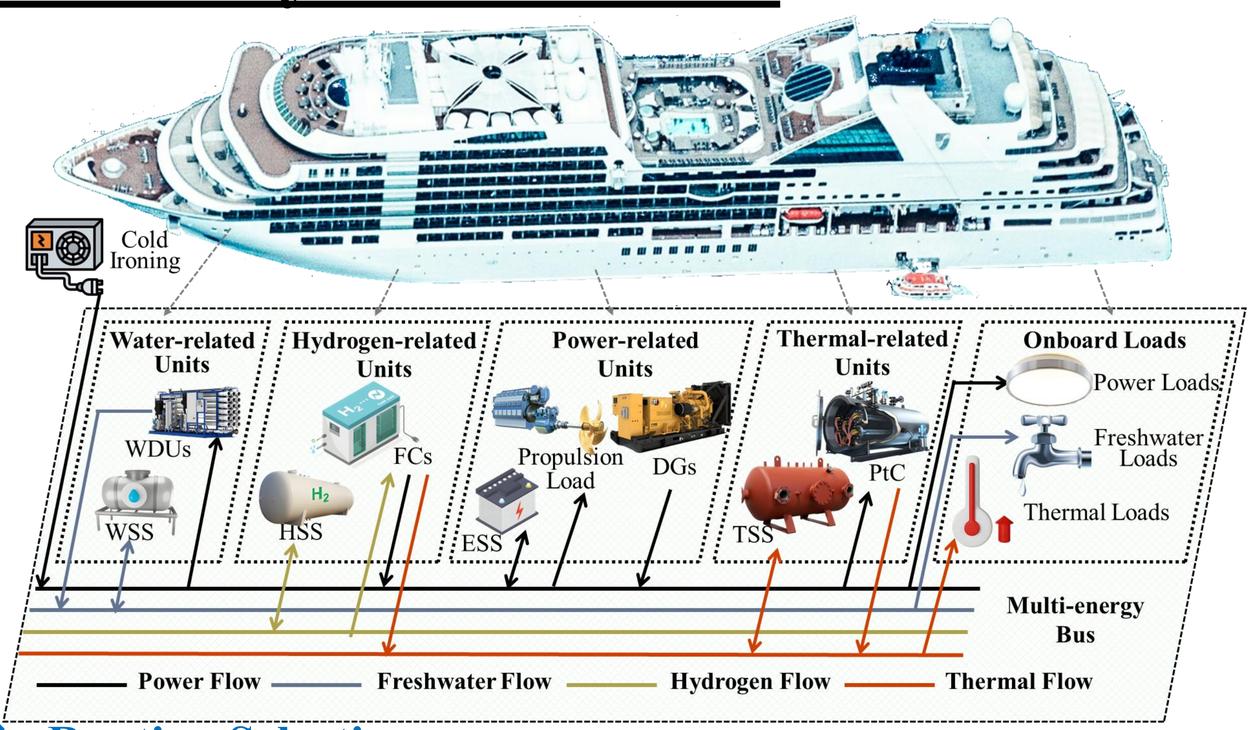
Background & Motivation

- Maritime transport contributes approximately **2.8% of global carbon dioxide emissions**, creating strong pressure for greener solutions.
- Modern cruise ships operate as **multi-energy ship microgrids (MESMs),** requiring electricity, thermal energy, freshwater, and **green hydrogen**.
- Nordic voyages face **uncertain weather**, including wind, waves, and drifting ice. These environmental factors directly affect propulsion loads.

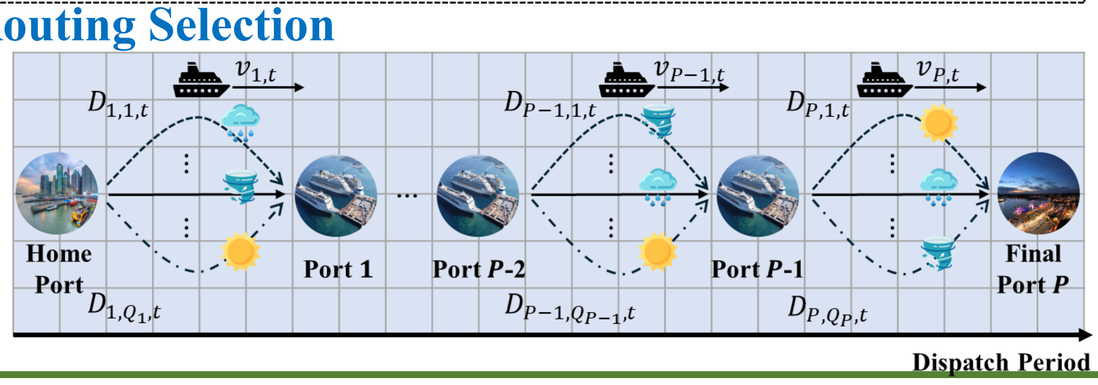
Main Contribution

- **Integrated Weather Routing + Multi-Energy Coordination.** Joint optimization of voyage path, ship speed, and onboard energy flows. Explicit propulsion load modeling considering wind, waves, drifting ice.
- **Risk-Averse Stochastic Framework.** Two-stage stochastic programming with CVaR. Rolling horizon adjustment during voyage.
- **Tailored Progressive Hedging (TPH) Algorithm.** Overcomes CVaR non-separability. Dynamic penalty adjustment.

General System Structure



Routing Selection

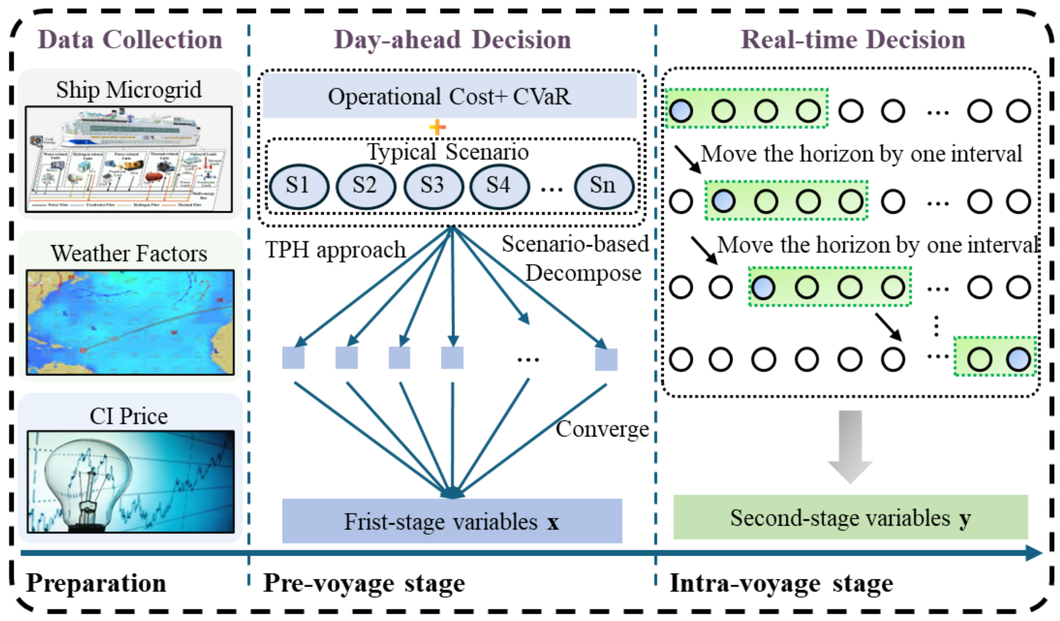


Objective Function

$$\min\left[(1-\eta)C_{all}+\eta\times CVaR_{\alpha}\left(C_{all}\right)\right]$$

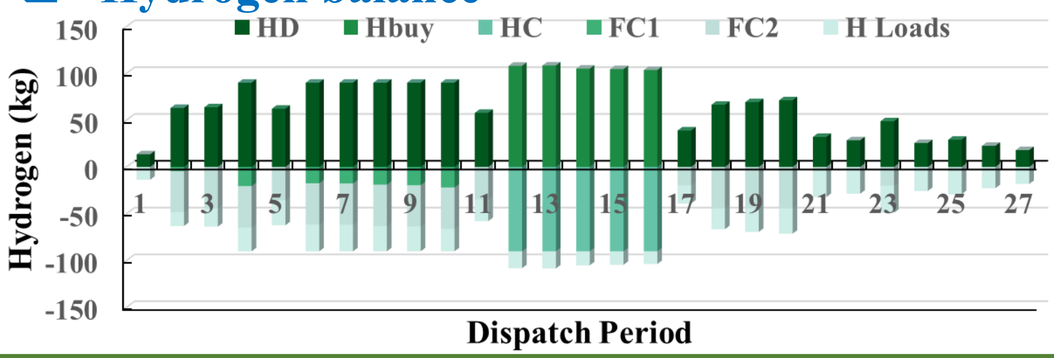
$$C_{all}=\sum_{t\in N_T}\underbrace{\left(C^t_{DG}+C^t_{EP}+C^t_{OM}+C^t_{CL}+C^t_{lig}+f^t_{En}\right)}_{f^t_{Ec}}\Delta t$$

Two-stage modeling framework

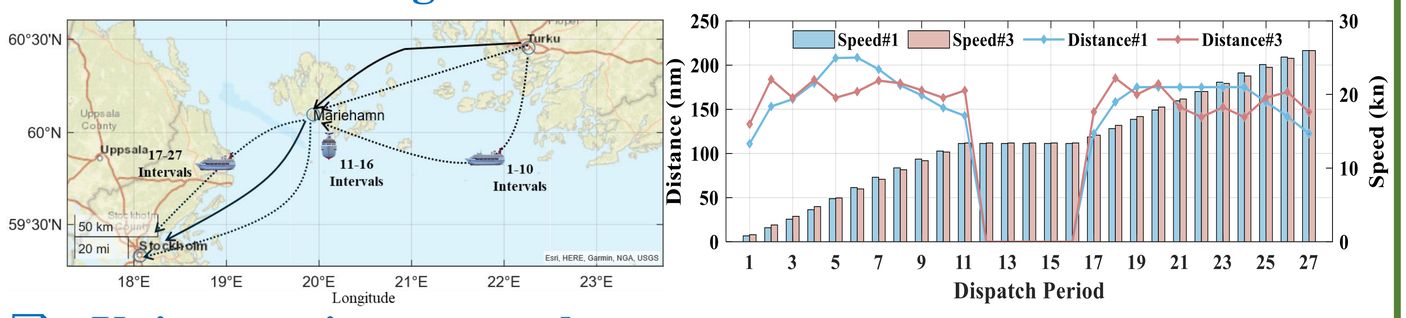


Simulation Results

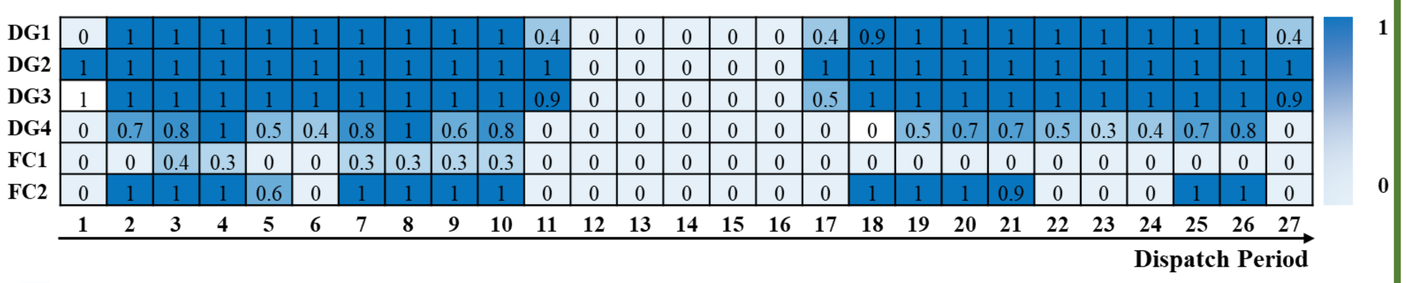
Hydrogen balance



Weather routing results



Unit commitment results



Comparative Analysis

- Case 1: The MESM operates with a predefined voyage route and speed.
- Case 2: The MESM strictly enforces multi-energy balance constraints.
- Case 3 : Our method

Cost ($)	Case 1	Case 2	Case 3
f_{Ec}	68,487.28	66,369.03	66,302.86
f_{En}	6,520.44	6,348.24	6,322.28
$CVaR$	79,454.13	78,340.92	77,401.68
Total	75,007.71	73,279.63	**73,102.79**

Computation Performance Analysis

Solution	Total Cost($)	Accuracy	Iteration	CPU (s)
Centralized	73,085.62	100%	-	3,116.5
PH	73,351.09	99.64%	15	352.6
TPH	**73,102.79**	**99.98%**	**14**	**190.4**

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