Decarbonization as a challenge for ship routing systems

Alex Topaj

DOO “Argestes”, Herceg Novi, Montenegro

Aleksandr Kondratenko

Technical University of Sofia, Sofia, Bulgaria

Chalmers University of Technology, Gothenburg, Sweden

Funded by the European Union

Shipbuilding
Ship design

Applied math
Simulation modeling

Software development

2016 – 2019

1894

2019 – 2022

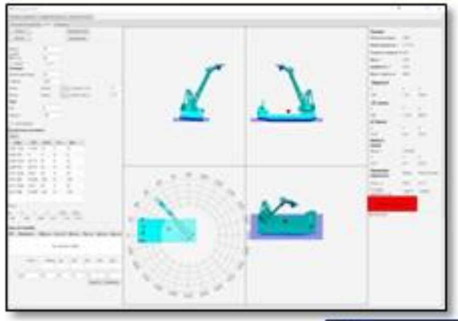
Бюро Гипербореа

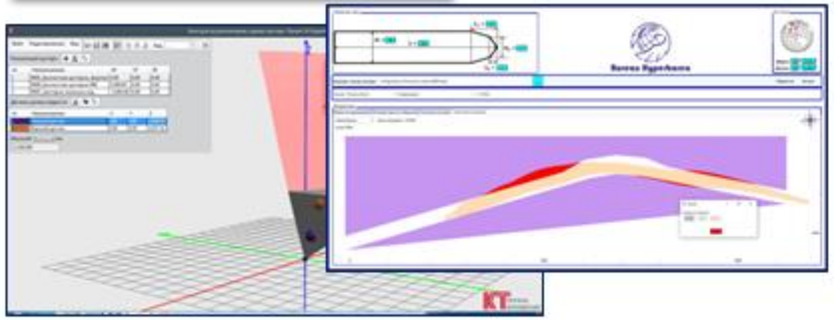
2025 – …

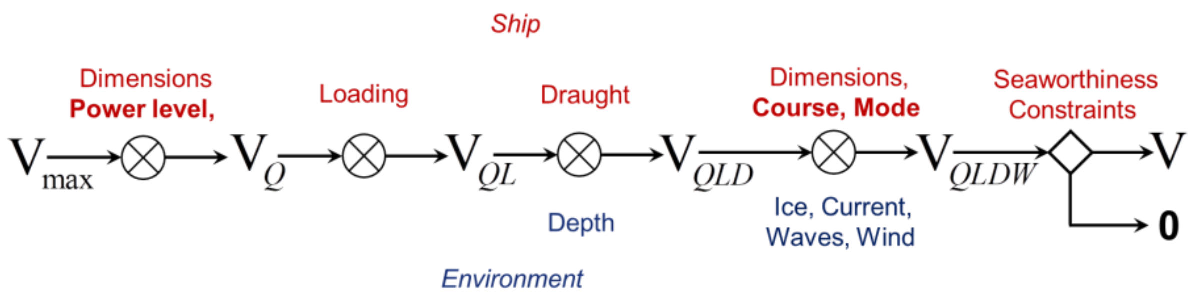
DOO Argestes

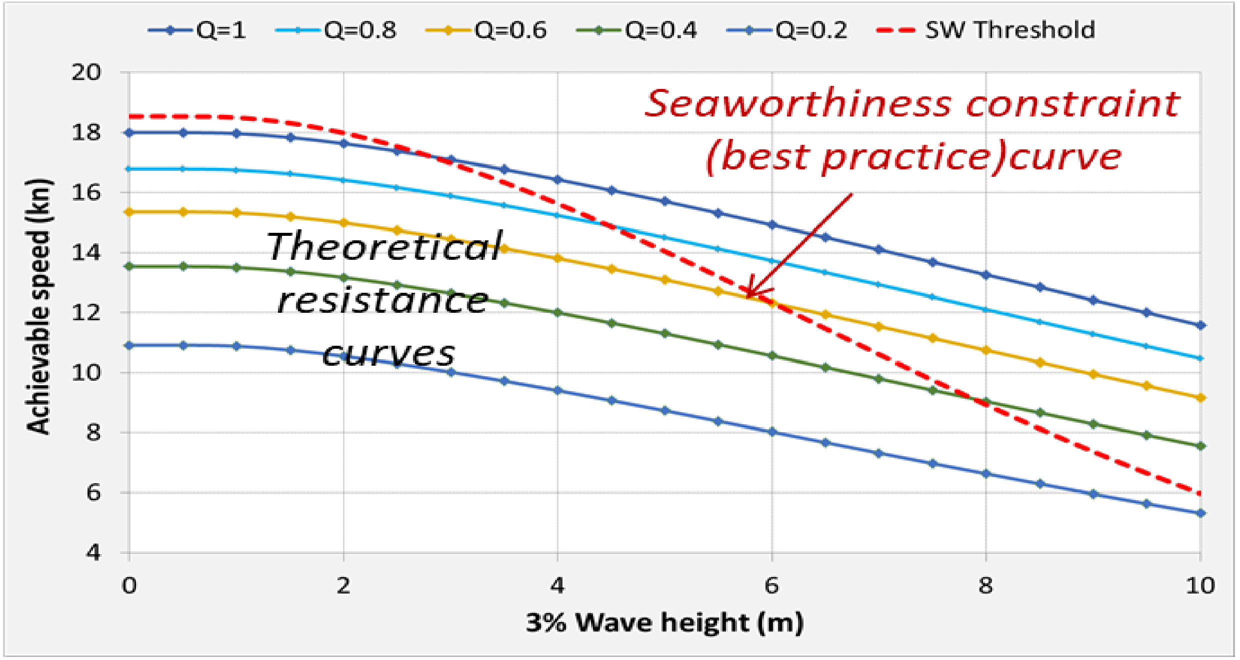
- Shipbuilding & Engineering Applications
- Simulation Models of Marine Transportation Systems
- Information Technologies & Software

Web-service of Ship Routing in Transocean Voyages







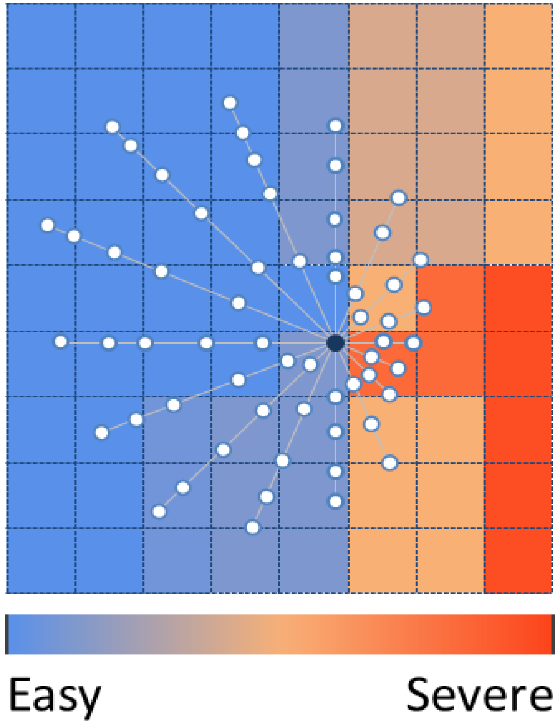


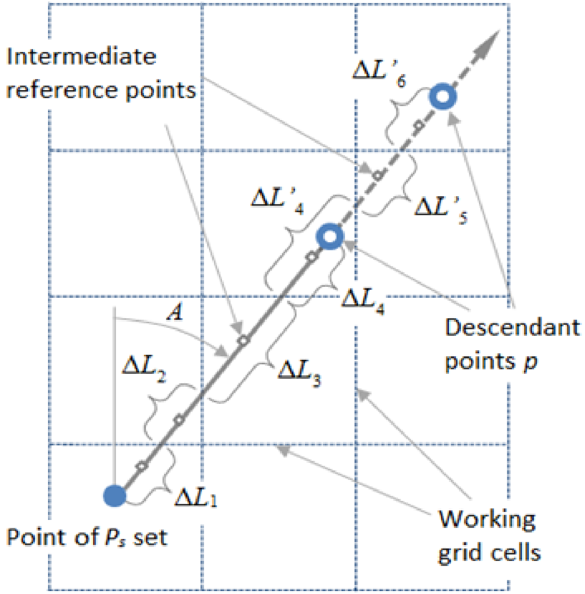
Advanced Model
of Ship Performance in Ice

Generalized Model of Ship Performance
in Open Water *and in Ice*

Topaj A., Tarovik O. (2024) Ship route planning in simulation models of Arctic transport systems. ***Proc. of the 26th Intern. Conf. on Harbor, Maritime and Multimodal Logistic Modeling & Simulation (HMS 2024)***

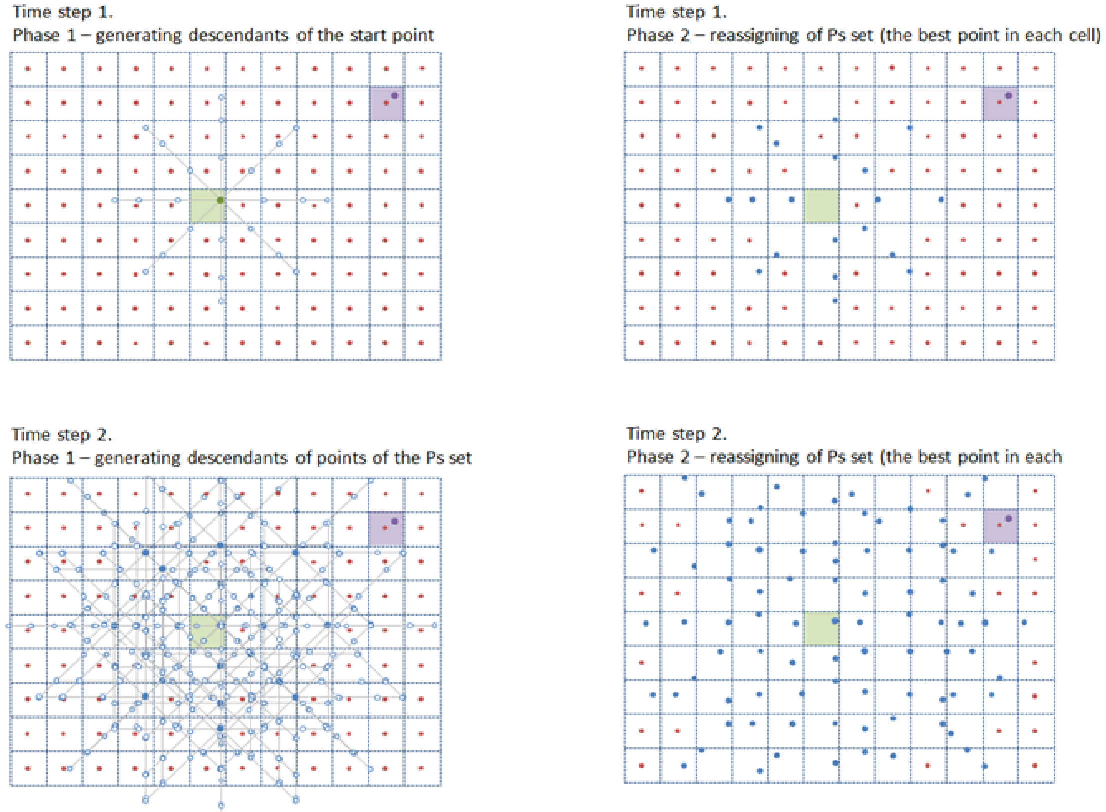
Funded by
the European Union





$$L(A,\gamma,\Delta t,s)=\sum_i \Delta L_i; \qquad \sum_i \Delta t_i = \Delta t;$$

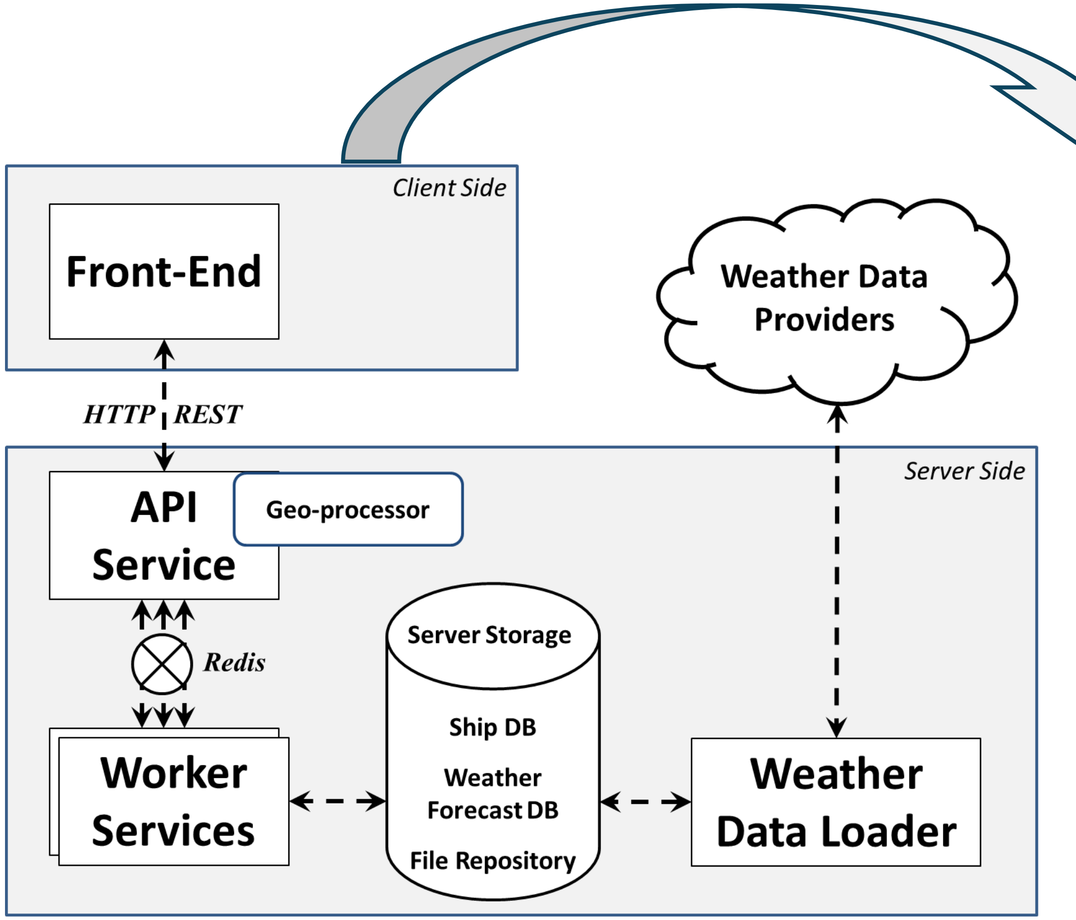
$$\Delta t_i = \frac{\Delta L_i}{V_i(\alpha,\gamma,s,\mathbf{E_i})}.$$



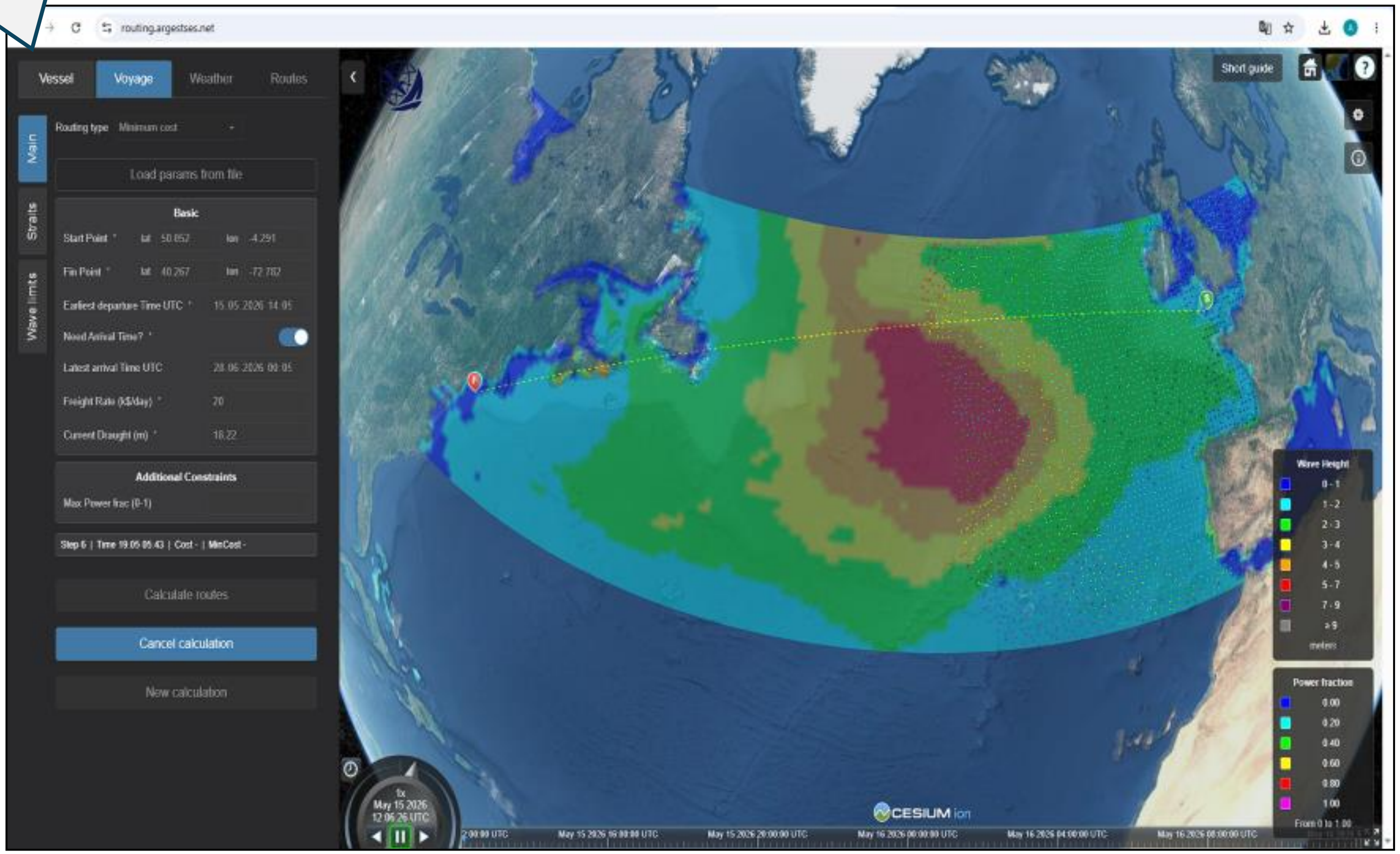
Wave-based Algorithm
of Ship Routing in Ice

Improved Hybrid Algorithm of Ship Routing
in Open Water *and in Ice*

Topaj A., Tarovik O. (2025) Hybrid cell-wave algorithm for ship routing in ice under spatiotemporal constraints.
***Ocean Engineering*, 326, 120863.**



Web-service of Ship Routing in Transocean Voyages

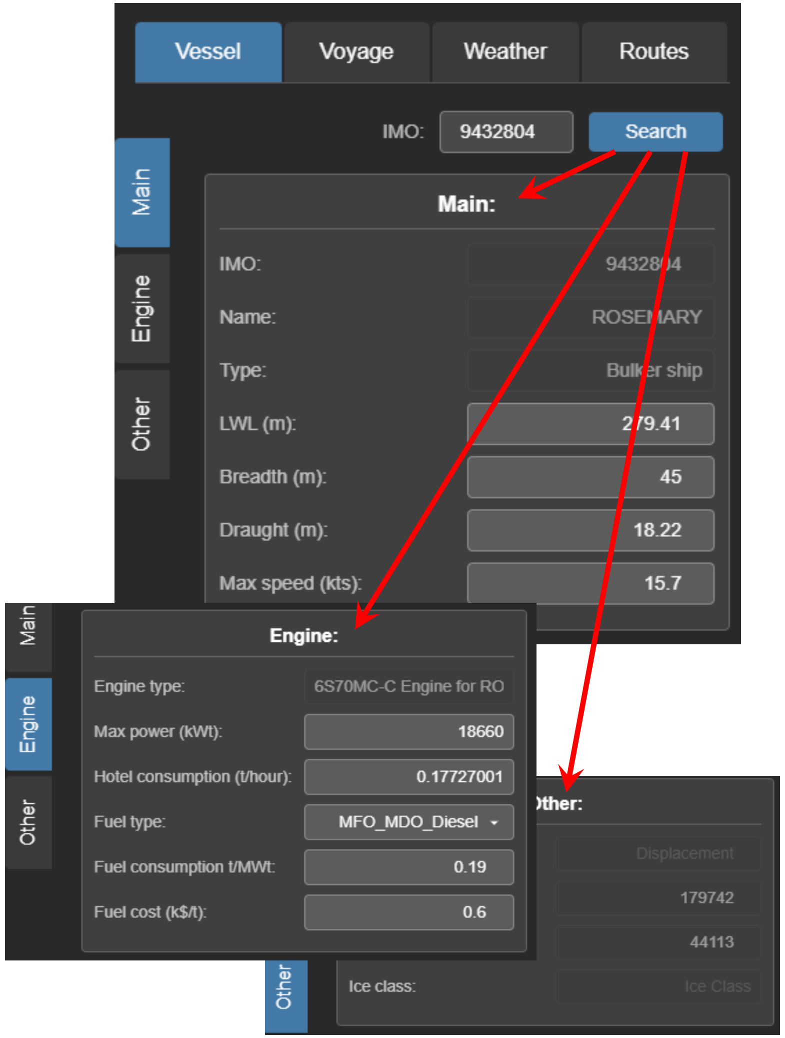


routing.argestses.net

Web-service of Ship Routing. Principal features & advantages

DEWATRA

- **Minimum entry threshold. No required input data about the ship except IMO. Built-in database of over 107,000 vessels across all major categories (tankers, gas carriers, bulkers, container ships, general cargo vessels, etc.) Default ship information model can be, however, edit and enriched by advanced user**
- Optimization of the ship trajectory together with shaft power and specific movement modes. Path planning for dynamically forecasted conditions in GIS-environment using actual weather forecasts from trustful providers (Copernicus, NOAA, ECMWF…). Support for ice and mixed navigation.
- Customized optimization criteria (fuel, time, emission, risk, distance) and constraints (fixed & free arrival/departure dates, voyage-dependent seaworthiness limitations). Account for canal tolls, strait queue delays, appointed passage time slots etc.
- Obtaining a family of recommended routes. Comparison & visual playback of alternatives to make the most informed strategic decision



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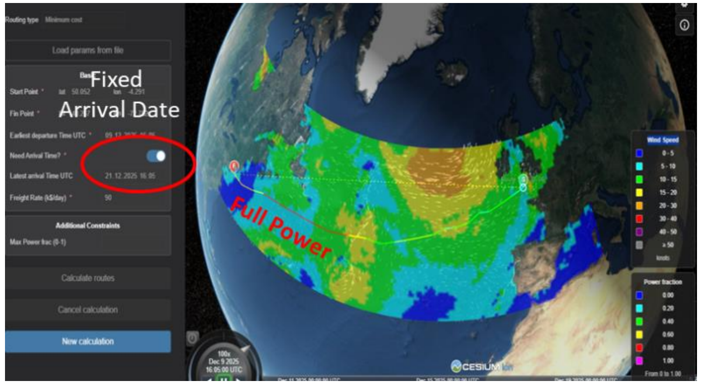

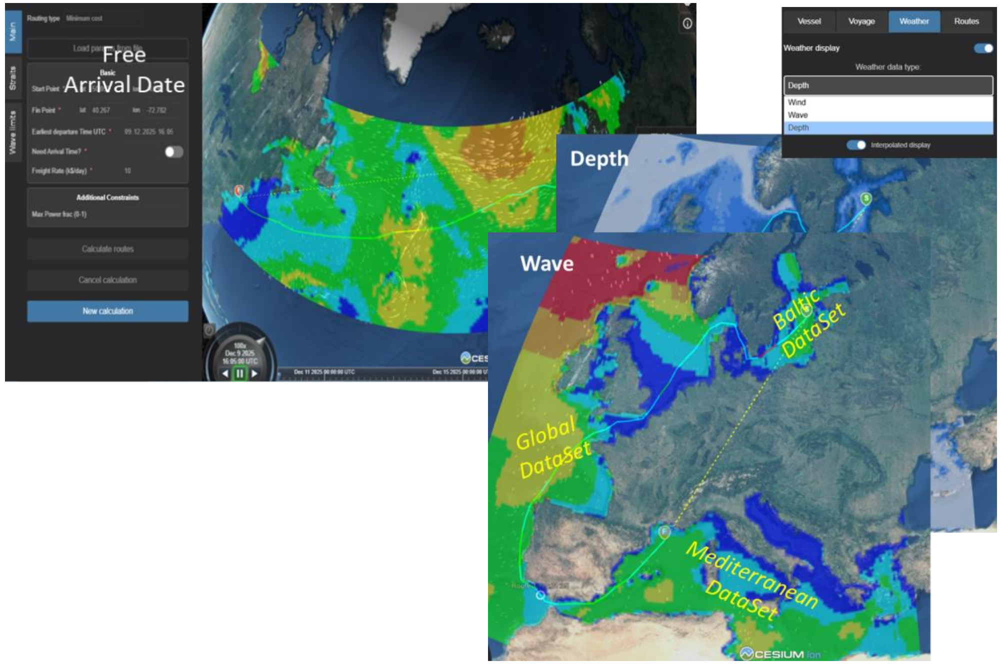

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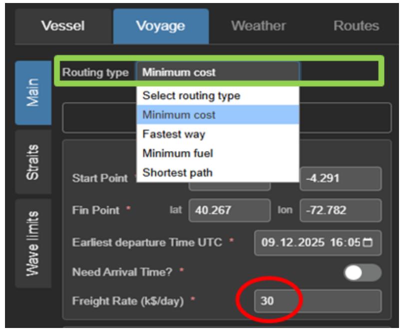

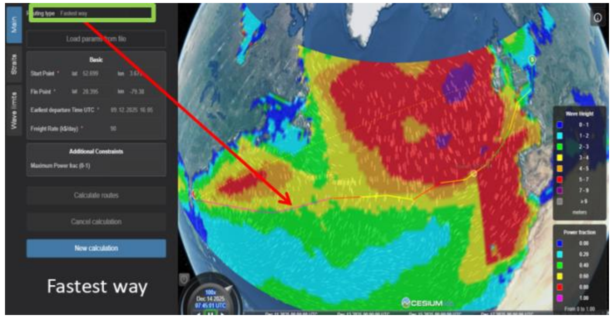

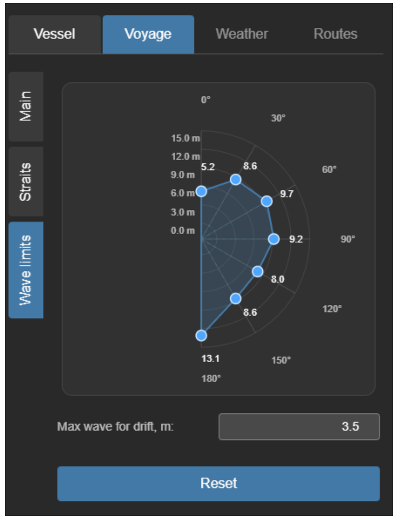

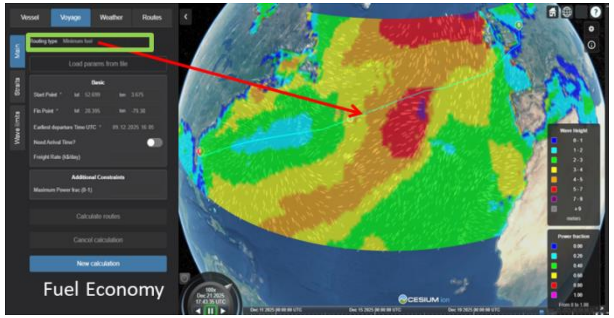

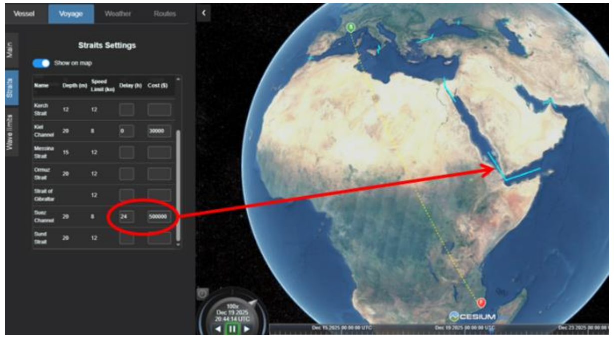

DEWATRA

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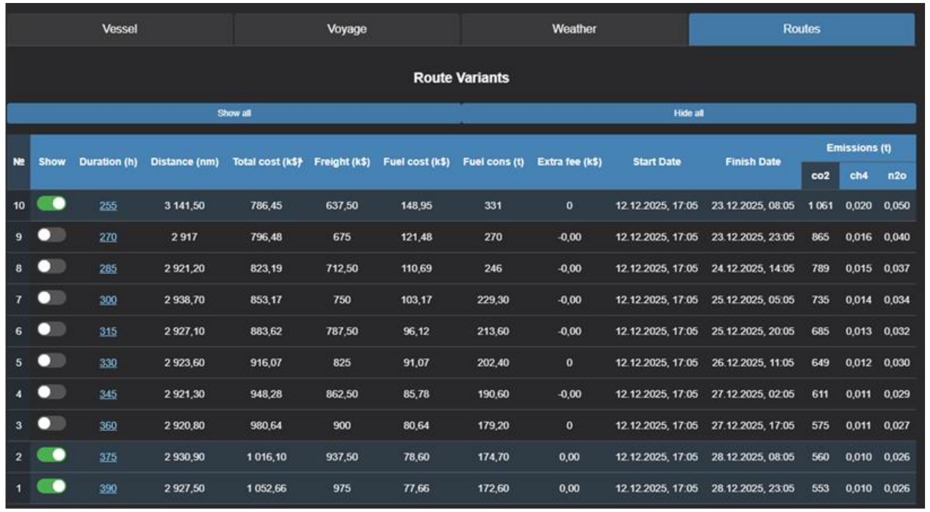
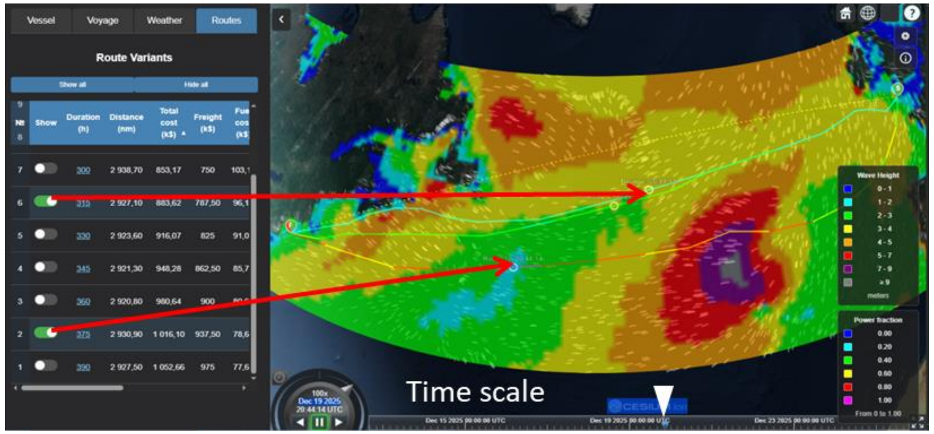


Vessel | Voyage | Weather | Routes

Route Variants

Show all | Hide all

№	Show	Duration (h)	Distance (nm)	Total cost (k$)	Freight (k$)	Fuel cost (k$)	Fuel cons (t)	Extra fee (k$)	Start Date	Finish Date	Emissions (t) co2	ch4	n2o
10	on	255	3 141,50	786,45	637,50	148,95	331	0	12.12.2025, 17:05	23.12.2025, 08:05	1 061	0,020	0,050
9	off	270	2 917	796,48	675	121,48	270	-0,00	12.12.2025, 17:05	23.12.2025, 23:05	865	0,016	0,040
8	off	285	2 921,20	823,19	712,50	110,69	246	-0,00	12.12.2025, 17:05	24.12.2025, 14:05	789	0,015	0,037
7	off	300	2 938,70	853,17	750	103,17	229,30	-0,00	12.12.2025, 17:05	25.12.2025, 05:05	735	0,014	0,034
6	off	315	2 927,10	883,62	787,50	96,12	213,60	-0,00	12.12.2025, 17:05	25.12.2025, 20:05	685	0,013	0,032
5	off	330	2 923,60	916,07	825	91,07	202,40	0	12.12.2025, 17:05	26.12.2025, 11:05	649	0,012	0,030
4	off	345	2 921,30	948,28	862,50	85,78	190,60	-0,00	12.12.2025, 17:05	27.12.2025, 02:05	611	0,011	0,029
3	off	360	2 920,80	980,64	900	80,64	179,20	0	12.12.2025, 17:05	27.12.2025, 17:05	575	0,011	0,027
2	on	375	2 930,90	1 016,10	937,50	78,60	174,70	0,00	12.12.2025, 17:05	28.12.2025, 08:05	560	0,010	0,026
1	on	390	2 927,50	1 052,66	975	77,66	172,60	0,00	12.12.2025, 17:05	28.12.2025, 23:05	553	0,010	0,026



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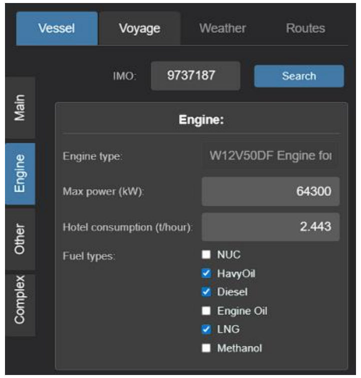
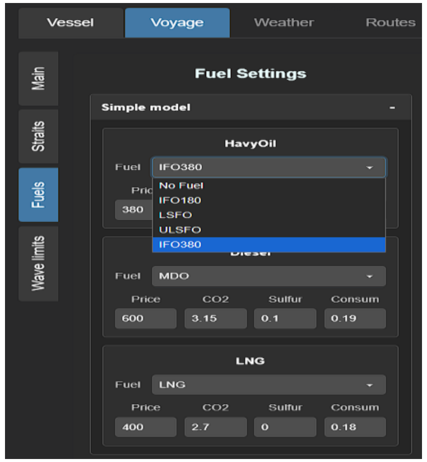
Vessel Definition:
Acceptable fuel types



Voyage input data:
Specific fuel for each type
(price, cons, emissions)

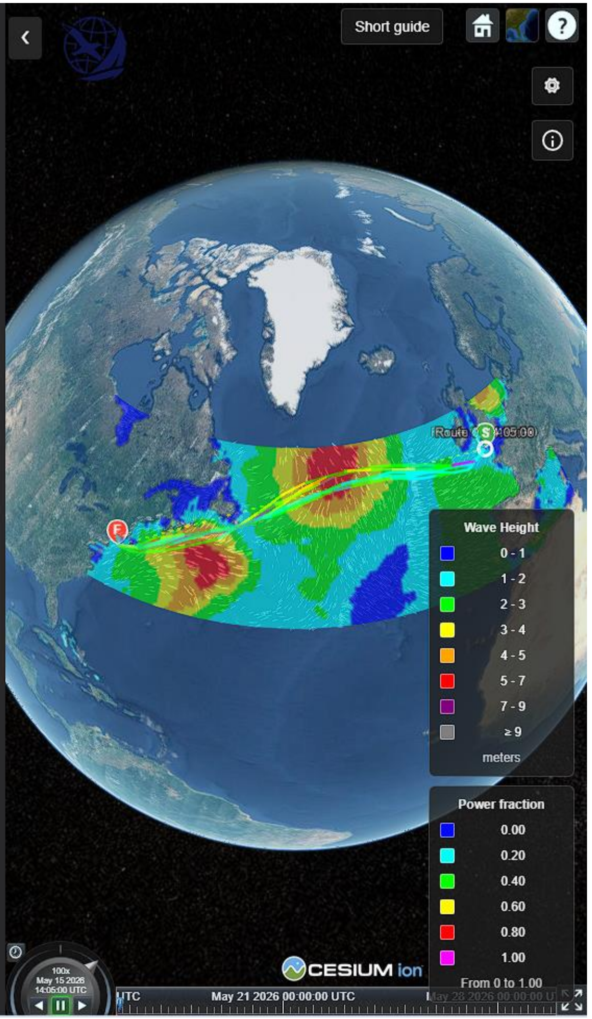


Vessel | Voyage | Weather | Routes

Route Variants

Show all | Hide all

№	Show	Duration (h)	Distance (nm)	Total cost (k$)	Freight (k$)	Fuel cost (k$)	Fuel cons (t)	Extra fee (k$)	Start Date (UTC)	Finish Date (UTC)	Emissions (t)			
											co2	ch4	n2o	CII
10		220.18	2,932.90	498.47	183.48	314.99	525	0.00	05/15/2026, 02:05 PM	05/24/2026, 06:15 PM	1,683	0.031	0.079	3.7
9		233.94	2,931.30	474.00	194.95	279.06	465.10	0	05/15/2026, 02:05 PM	05/25/2026, 08:01 AM	1,491	0.028	0.070	3.3
8		247.70	2,931.30	458.94	206.42	252.52	420.90	0	05/15/2026, 02:05 PM	05/25/2026, 09:46 PM	1,349	0.025	0.063	3.0
7		261.46	2,921.30	452.48	217.88	234.60	391	0	05/15/2026, 02:05 PM	05/26/2026, 11:32 AM	1,254	0.023	0.059	2.8
6		275.22	2,915.60	447.27	229.35	217.92	363.20	-0.00	05/15/2026, 02:05 PM	05/27/2026, 01:18 AM	1,164	0.022	0.054	2.6
5		288.98	2,917.60	444.04	240.82	203.22	338.70	0	05/15/2026, 02:05 PM	05/27/2026, 03:03 PM	1,086	0.020	0.051	2.4
4		302.74	2,925.50	441.97	252.29	189.69	316.10	-0.00	05/15/2026, 02:05 PM	05/28/2026, 04:49 AM	1,014	0.019	0.047	2.3
3		316.50	2,919.90	439.98	263.75	176.22	293.70	-0.00	05/15/2026, 02:05 PM	05/28/2026, 06:35 PM	942	0.018	0.044	2.1
2		330.26	2,924.60	439.16	275.22	163.94	273.20	0	05/15/2026, 02:05 PM	05/29/2026, 08:20 AM	876	0.016	0.041	1.9
1		344.03	2,896.30	451.20	286.69	164.51	274.20	-0.00	05/15/2026, 02:05 PM	05/29/2026, 10:06 PM	879	0.016	0.041	2.0

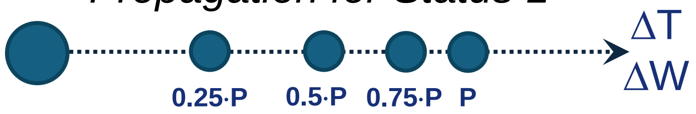


Emission Control Areas. Fuel as an optimization variable

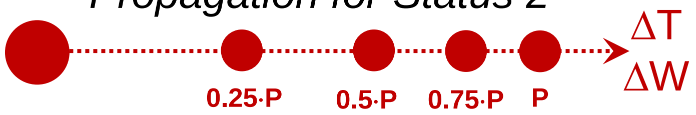
DEWATRA

«Status» - additional discrete optimization variable

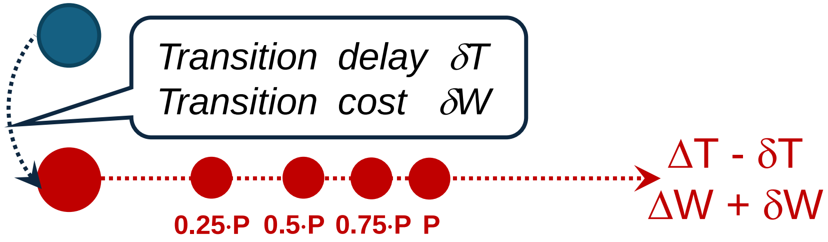
Propagation for Status 1



Propagation for Status 2



Propagation with change of Status

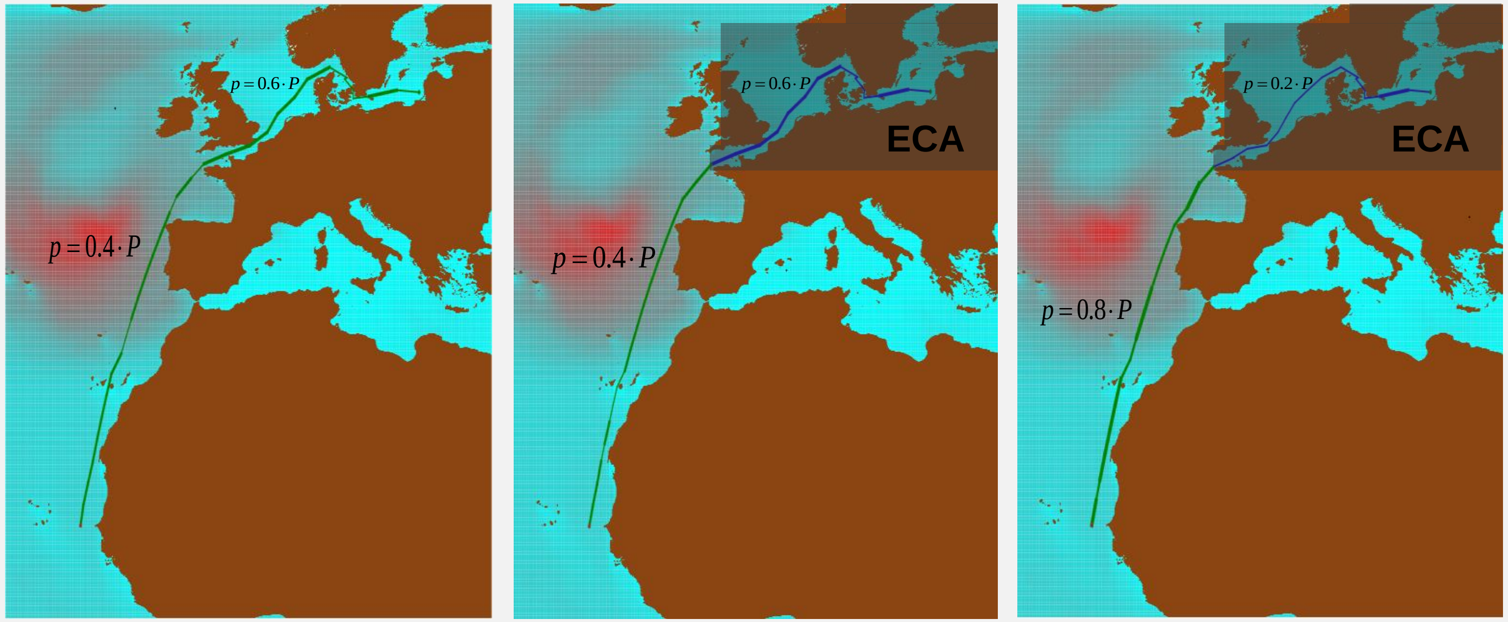


The formal regulation of emission control areas may lead to an increase in overall emissions!

Case 1: <u>Vessel:</u> large bulk carrier; <u>Voyage:</u> Klaipeda-Dakar; Strict delivery deadlines

2 possible fuels: "dirty" fuel (e.g. heavy oil); "allowed" fuel (e.g. diesel or LNG)

$C_{FUEL2} = 1.05 \cdot C_{FUEL1}$ $C_{FUEL2} = 1.05 \cdot C_{FUEL1}$ $C_{FUEL2} = 3 \cdot C_{FUEL1}$



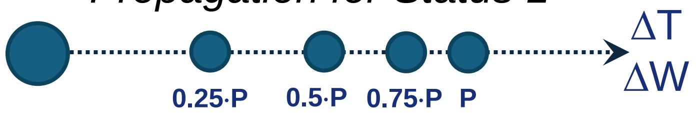
<u>Result:</u> If the permitted fuel is significantly more expensive than the standard one, then the vessel operates **at minimum power** (economy mode) in emission control area, and **at full power** (with high emissions) - for the remaining part of the voyage

	Route 1	Route 2
Total Fuel Consumpt. (t)	423	441
Cost (USD) Chip Diesel	258824	445638
Cost (USD) Exp. Diesel	279318	433758

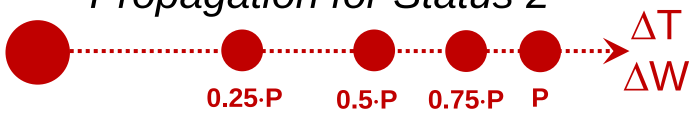
Emission Control Areas. Fuel as an optimization variable

«Status» - additional discrete optimization variable

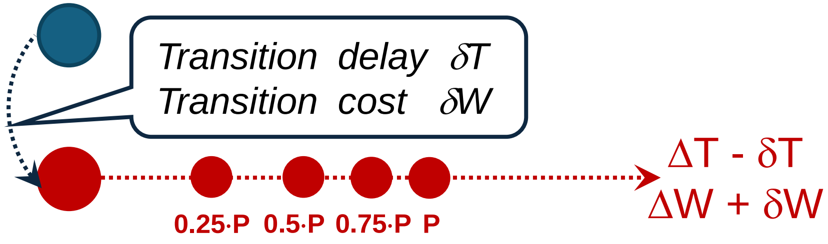
Propagation for Status 1



Propagation for Status 2



Propagation with change of Status

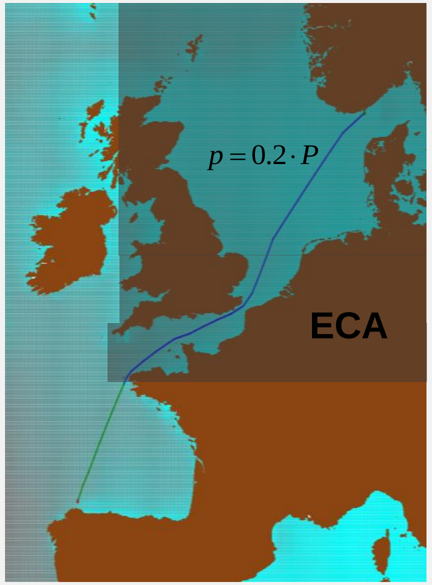


The formal regulation of emission control areas may lead to an increase in overall emissions!

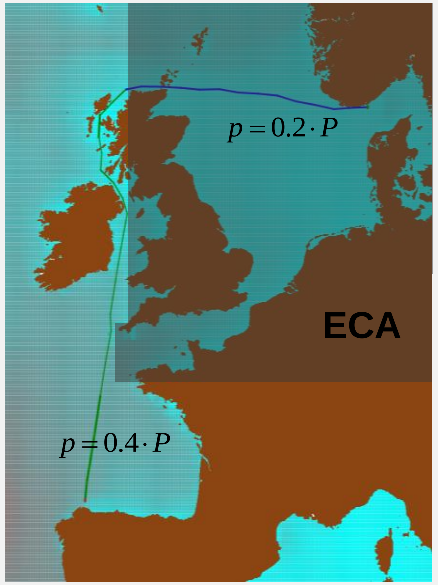
Case 2: Vessel: large bulk carrier; Voyage: Kristiansand - A Coruna; Flexible delivery time

2 possible fuels: (green line) “dirty“ fuel (e.g. heavy oil); (blue line) "allowed" fuel (e.g. diesel or LNG)

$C_{FUEL2} = 1.05 \cdot C_{FUEL1}$



$C_{FUEL2} = 3 \cdot C_{FUEL1}$



Result: If the permitted fuel is significantly more expensive than the standard one, then the vessel is taking a longer route (past Ireland rather than through the English Channel) to shorten its passage through the Emission Control Area

	Route 1 Cost (USD)	Route 2 Cost (USD)
Chip Fuel (1)	**67058**	445638
Exp. Fuel (2)	85329	**160131**

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As any problem of mathematical optimization, ship routing problem is described by **variables**, **criterion**, and **constraints**.

The **variables** are *trajectory*, current *power level* of the ship power plant and the *modes* of movement (bow- or aft-forward for DAP ships, fuel type, etc.)

The only significant **criterion** or score for commercial shipping is the *profit* from the voyage in monetary terms

Thus, all additional considerations (risks, sustainability) should be presented either as **components** of the monetary **criterion** or in the form of explicit **constraints** (local or terminal ones)

Issue	Constraint Representation	Score Representation
Voyage Time	ETA, Time window for delivery, etc.	Penalty for delay
Navigation Risks	Seaworthiness limitations, POLARIS indices, etc.	Penalties for risks
Sustainability	ECA, Emission limits, etc.	Fines for emissions and pollution

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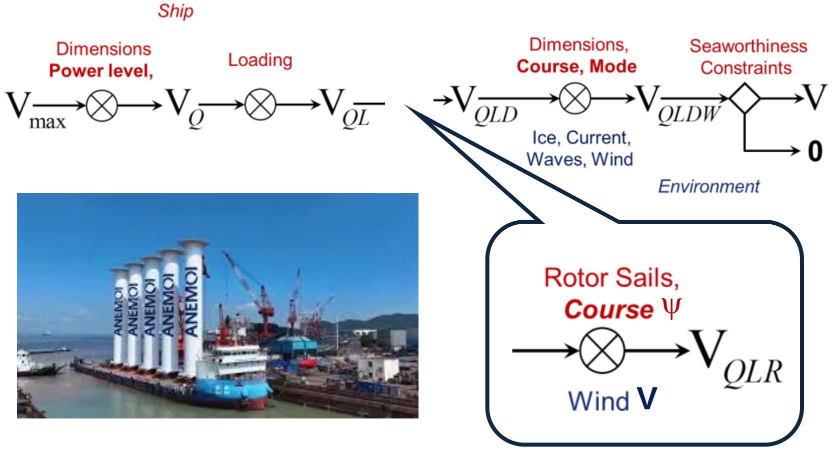
Ship transit model



$$V_{QLR} = V_{QL} \cdot \sqrt{1 + \frac{(F_L - F_D) \cdot V_{QL} - W_R}{W_S \cdot Q}}$$

$F_L = F_L(\psi, \mathbf{V})$ - lift force

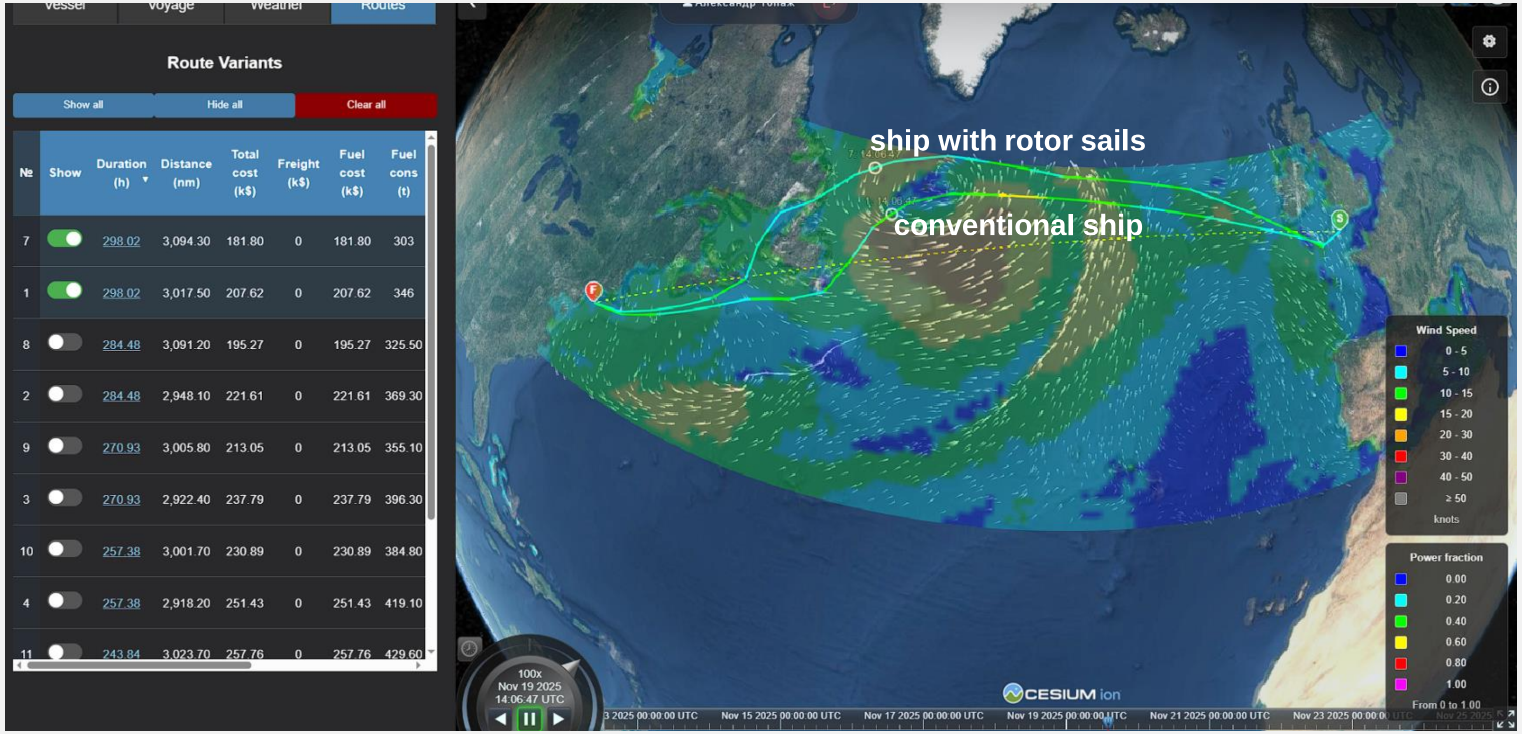
$F_D = F_D(\psi, \mathbf{V})$ - drag force

W_R - sail rotation power

W_S - total shaft power

Q - current power fraction

Case 1: Vessel: large bulk carrier; Voyage: Plymouth – New York; Flexible delivery time
Actual weather forecast from 12.11.2025

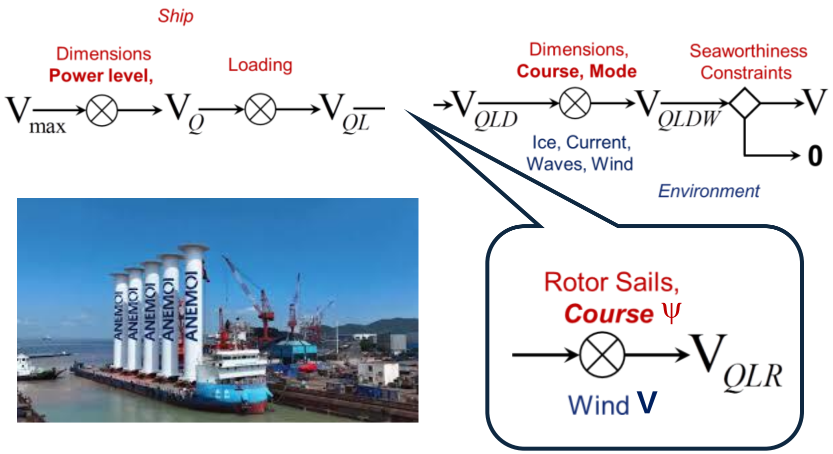


№	Show	Duration (h)	Distance (nm)	Total cost (k$)	Freight (k$)	Fuel cost (k$)	Fuel cons (t)
7		298.02	3,094.30	181.80	0	181.80	303
1		298.02	3,017.50	207.62	0	207.62	346
8		284.48	3,091.20	195.27	0	195.27	325.50
2		284.48	2,948.10	221.61	0	221.61	369.30
9		270.93	3,005.80	213.05	0	213.05	355.10
3		270.93	2,922.40	237.79	0	237.79	396.30
10		257.38	3,001.70	230.89	0	230.89	384.80
4		257.38	2,918.20	251.43	0	251.43	419.10
11		243.84	3,023.70	257.76	0	257.76	429.60

- Equipping the vessel with rotor sails allows for a 12.5 percent fuel economy for the voyage under consideration.
- The optimal route for a vessel with rotor sails differs significantly from the route for a conventional vessel.

DEWATRA

Ship transit model



$$V_{QLR} = V_{QL} \cdot \sqrt{1 + \frac{\left(F_L - F_D\right) \cdot V_{QL} - W_R}{W_S \cdot Q}}$$

$F_L = F_L(\psi, \mathbf{V})$ - lift force

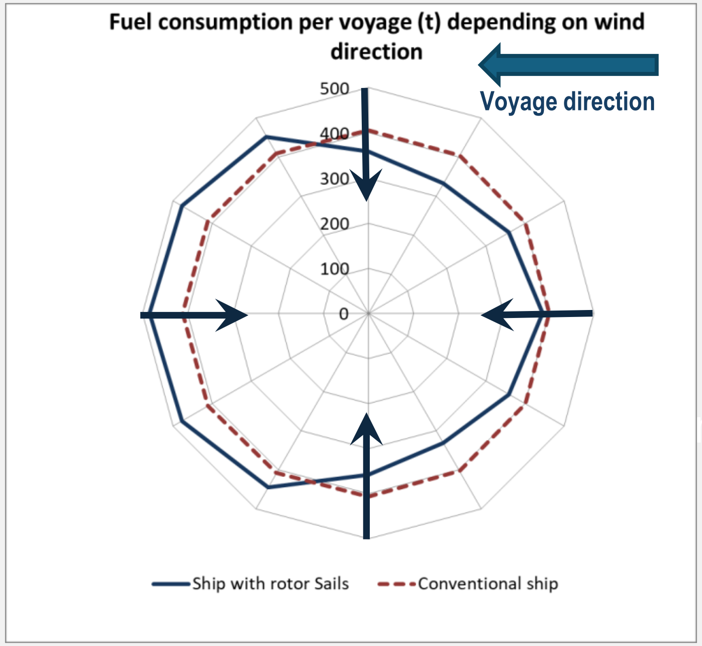
$F_D = F_D(\psi, \mathbf{V})$ - drag force

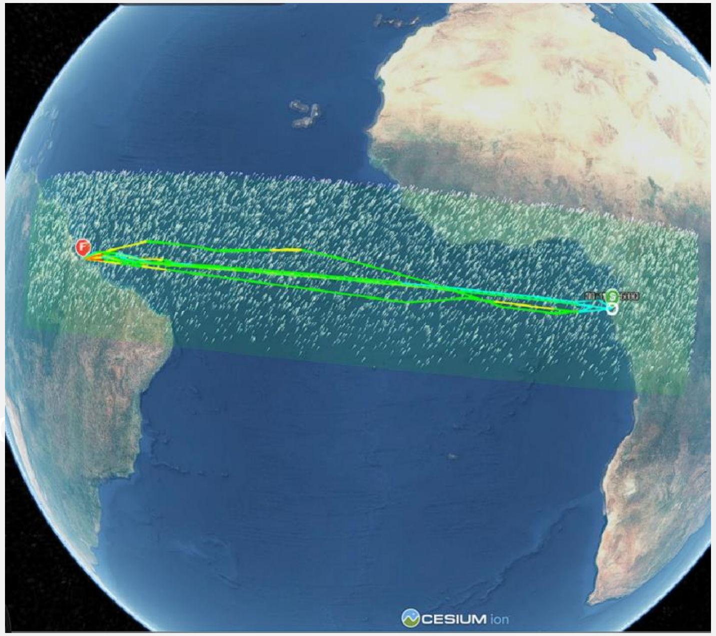
W_R - sail rotation power

W_S - total shaft power

Q - current power fraction

Case 2: Vessel: large bulk carrier; Voyage: Along the equator from east to west; Sufficient ETA; Synthetic weather: no waves, wind in one direction 10 m/s





- The maximum fuel economy due to rotor sails (at the angles providing the greatest lift) reaches 18% (only 2% for real weather)
- The optimal route sometimes differs from the orthodromy (the ship " is tacking" trying to find the best wind).
- In unfavorable conditions, rotor sails can have a negative effect due to increased aerodynamic drag.

Further development of ship routing services for the purposes of waterborne transportation decarbonizing:

- **Electric propulsion vessels:** Route optimization for the voyages with limited resources (fuel or battery capacity)
- **Adaptive routing:** Assimilation of actual on-board measurements of environmental data and emissions
- **Autonomous and/or unmanned vessels:** Revision of traditional seaworthiness requirements and constraints
- **Robust probabilistic routing:** Accounting for the decline in confidence in weather forecasts for long time horizon
- **Simulator for research and training:** Retrospective analysis of past voyages and emission assessment
- **Long-term and strategic planning:** Ensemble climate-base routing and climate change scenarios
- **New tools and approach:** Integration of AIS-based AI-methods in optimization logic and ship propulsion models

Conclusions:

- Improving **ship operations** may lead to increased energy efficiency (fuel economy and reduced emissions) comparable to those of more expensive technical solutions.
- Weather routing services and software is a promising direction in the field of automation and informatization of waterborne cargo transportation.
- They must be developed to become user-friendly decision support tools that are in demand in the real practice of sustainable and decarbonization-oriented shipping.
- Anyway, they should be used just now as a proper simulator for testing new technical solutions and regulations.

Kondratenko, A., Kamberov, K., Todorov, G. (2025) Decarbonizing waterborne transport in a developing country: Challenges and opportunities. *Case Studies on Transport Policy.* 21. 101516.

Thank you for attention!

Any questions?

and welcome aboard…

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