AI Voyage Optimization System *(AIVOS)*

AI based decision support tool for voyage planning taking weather forecast uncertainties and ship responses into considerations

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Every ship captain or manager is faced with the difficult task of planning a safe and efficient passage to arrive at the next port on schedule using the least fuel. Their decisions are sometimes complicated by charter party and regulatory requirements as well as anticipated navigation hazards, engine downtimes, and environmental concerns. Last but not least are the unpredictable storms during a long voyage. Contracted by charterers or ship managers before a ship's departure, a weather routing service provider typically emails a so-called "optimized" route to ship, with the objective of convincing the captain to choose it over other standard routes. The selected route may then be updated periodically during the voyage with the latest weather forecast and ship positions, either by the shore-based service or using weather routing software.

Most weather routing companies use one source of deterministic wind and wave forecast as input to their routing algorithms. While major weather centers around the world produce long range forecasts beyond 15 days, acceptable accuracy for wind and wave conditions around major storms is normally up to 5 days, and even shorter in tropical storms for ship routing purpose. This is due to the inherently chaotic nature of the earth's atmosphere and the imperfect depiction of its initial state. An omitted small disturbance can develop into a major storm several days later. Unexpected changes in storm track and intensity can drastically affect the safety and expected fuel consumption of a ship voyage not to mention its planned ETA. Unless these uncertainties are quantified and included in the voyage planning, the so-called optimized voyage is just a marketing term, not to mention the unproven claim of saving 5-10% fuel every voyage.

Another challenge is how to translate these changing wind and wave conditions into ship responses and seakeeping events as safety measures. Simply avoid storms without predicting pitch/roll responses and acceleration for the specific ship loading conditions could lead to dangerous situation such as synchronous or parametric roll resonance. Excessive trim by the bow could lead to propeller racing, risking engine shut down in a storm. Performance models simply based on past noon reports will lead to unreliable prediction of fuel consumption and ETA..

Although every weather routing company and new start-up touts their superiority of technology and service, it is difficult to consistently prove that their approaches are better than others when weather forecast and operational uncertainties can turn a perfectly planned voyage into a disaster. Every year, thousands of containers are damaged by heavy weather or lost overboard while these ships were under weather routing. Cargo insurance and speed/fuel claims stipulated in charter parties have kept maritime lawyers busy, not to mention the resulting environmental impacts of lost containers in the ocean. The unproven claims of saving 5-10% fuel every voyage with thousands tons of Greenhouse Gas reductions a year also creates doubts of how effective these services can contribute to the overall de-carbonization effort for the shipping industry.

Our Artificial Intelligence based Voyage Optimization System (AIVOS) utilizes machine learning (ML) in weather forecast and ship performance modeling to improve the safety and efficiency of voyage execution by providing a real-time decision support tool. Instead of one deterministic forecast, AIVOS uses an ensemble of wind and wave forecasts to simulated and optimize planned routes. Histograms and statistics on ship motion responses and performances are then compiled so the user can select the optimal route based on response threshold limits and other voyage KPIs with quantified uncertainties. The software tool consists of the following elements:

1. Ensemble forecast from the US National Oceanic Atmospheric Administration (NOAA)'s Global Ensemble Forecast System (GEFS) which issues one nominal forecast (#0) plus 30 ensemble members up to 15 days.
2. High Resolution ocean surface current forecast up to 8 days;
3. Customized Ship Motion Program to predict motions response, seakeeping events and added resistance in waves for specified loading conditions;
4. Ship propulsion model to predict resistances, engine horse power and RPM to maintain speed and heading;
5. Dynamic Programming algorithm for Route optimization on a user defined grid;
6. Optimum Speed management for Just In Time arrival;
7. Optional Ship performance "Black Box" data recorder to collect motion and operation data in real-time;
8. AI/M algorithms for updating of ship performance model using recorded voyage data.

High speed multi processor cloud computing facilities (AWS) are utilized to download and process the forecast weather, perform motion prediction and update ship models. Vast amount of cloud storage spaces are required to store the 31 members of 15 day global high resolution global wind and wave forecast data, plus recorded historic ship performance data as well as library of the latest update of performance and motion prediction models.

To show the uncertainties, AIVOS user can click and select any grid points associated with specific forecast horizon based on the 31 member ensemble wave forecast, as depicted by the histograms and related statistics.

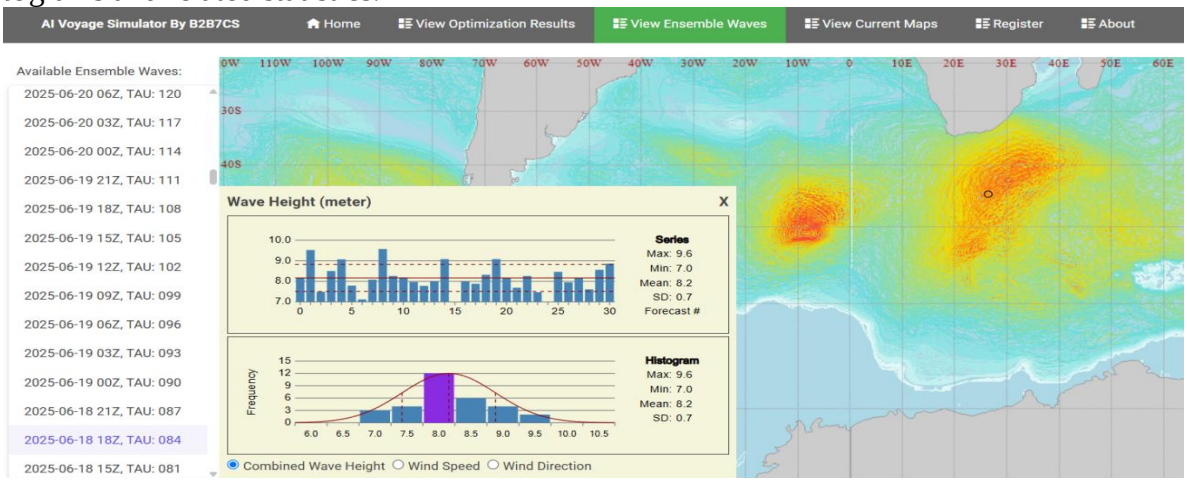


Figure 1. Plot of 31 forecast variations with statistics. (0) and Purple indicate the official forecast

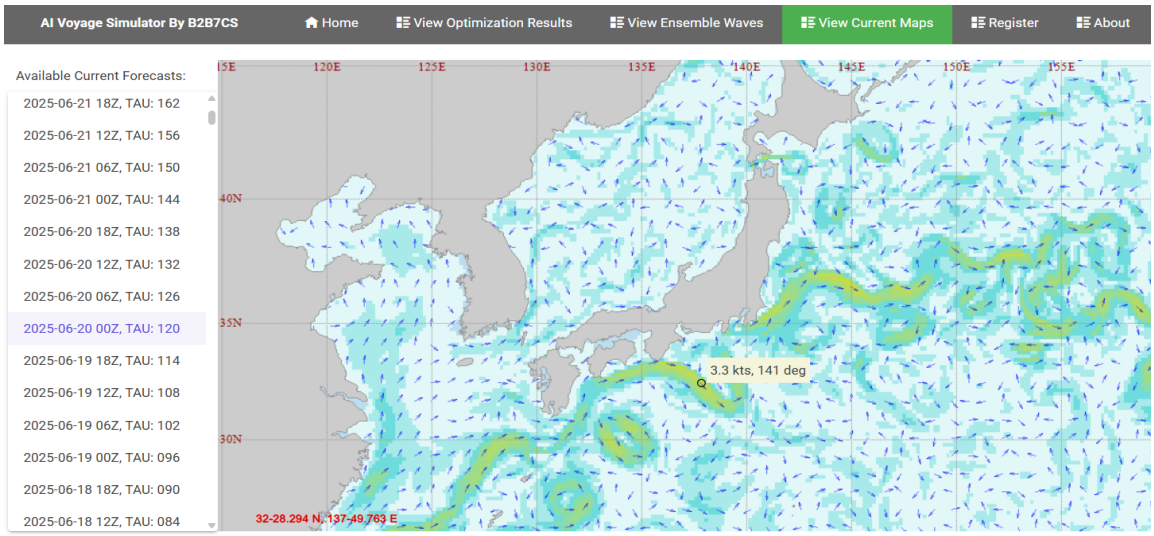


Figure 2. High resolution ocean surface current out to 8 days

AIVOS also utilizes AI/ML, optimization algorithm and naval architecture tools to create ship performance models using ship specific design data, noon reports and real-time ship data. Once it is set up, the user can import routes for simulation or create/modify/optimize routes on a PC. This Software as a Service (SaaS) can be accessed anywhere in the world with an internet connection.

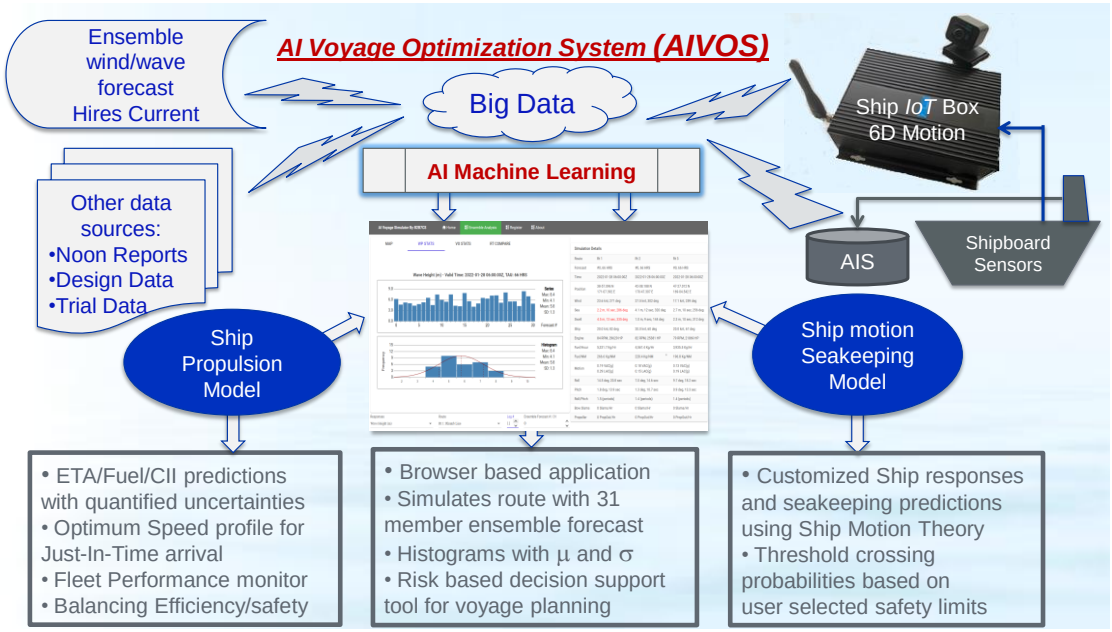


Figure 3. Flow chart depicts the elements of AIVOS and capabilities

Setting up a Voyage

Click on Voyage menu to start setting up a voyage:

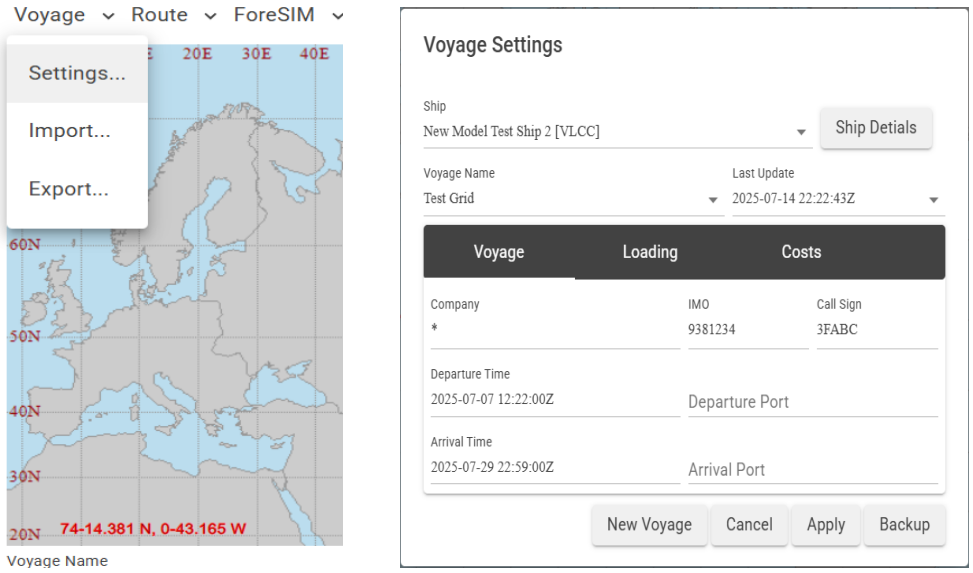


Figure 4. Setting up a New Voyage with desired ETD and ETA

After setting up the ETD and ETA, user can specify the ship's loading condition, fuel cost and other environmental parameters associated with the voyage. Up to THREE routes with the same ETD can be created for comparisons.

Create, import and modify routes

Click on Route menu allows user to create, modify and save routes

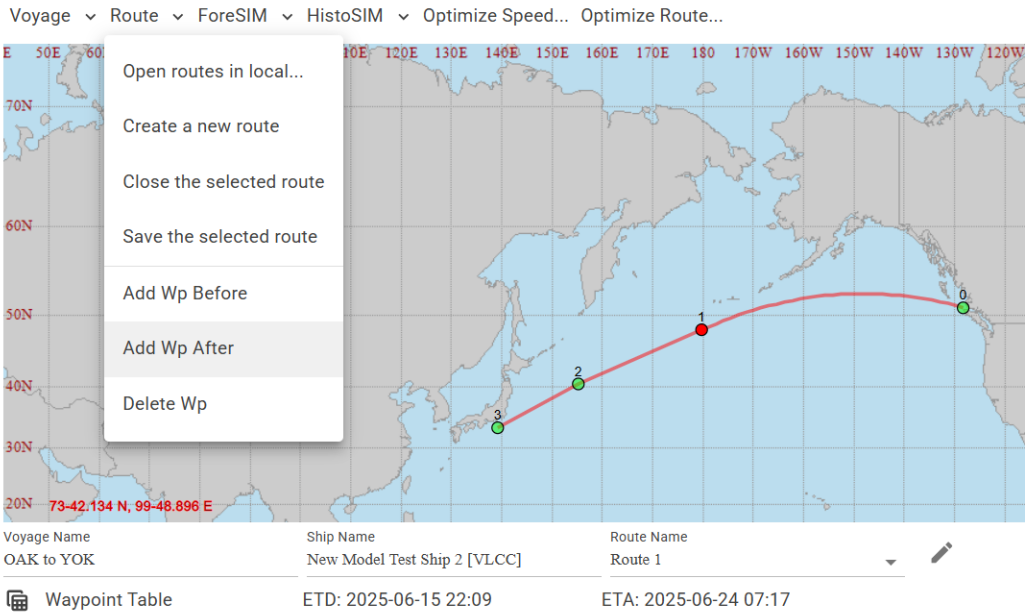


Figure 5. Creating a route by clicking and dragging mouse on the map.

Clicking on Waypoint Table allows user to edit waypoint properties. Clicking on Waypoint Table again will hide the table. Average required speed will be automatically calculated for the desired ETD/ETA if Fixed ETA is selected. The table will scroll for more waypoints.

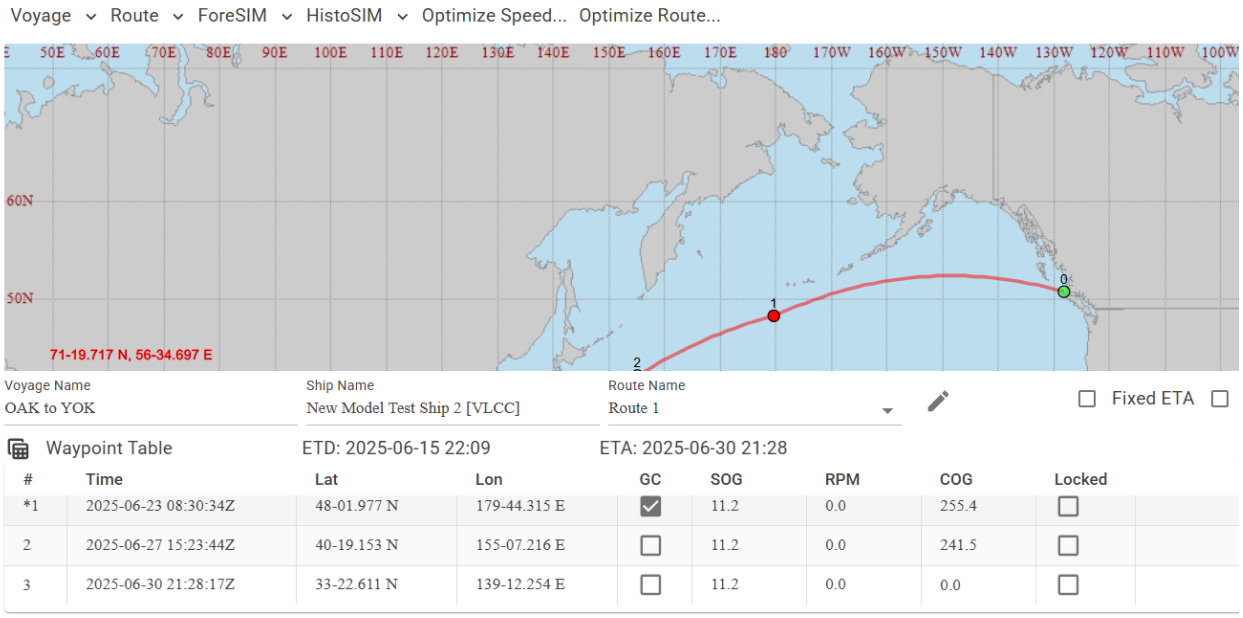


Figure 6. Editing waypoint and speed along a route.

Simulate Routes with forecast and analysis data

There are two types of simulation. One uses the forecast data for ongoing voyage planning. The other uses archived analysis data of NOAA's official forecast to generate voyage statistics. (See examples in later sections) User can select using Single Official Forecast (member #0) or all 31 members in the ensemble.

Click on ForeSim will start the simulation of all user created routes according the ETD and ETA. Because the amount of computation and number of simulation requests, AIVOS will assign an ID so the user can retrieval it later for reviewing the results. This allows the user to manage multiple ships and multiple voyages.

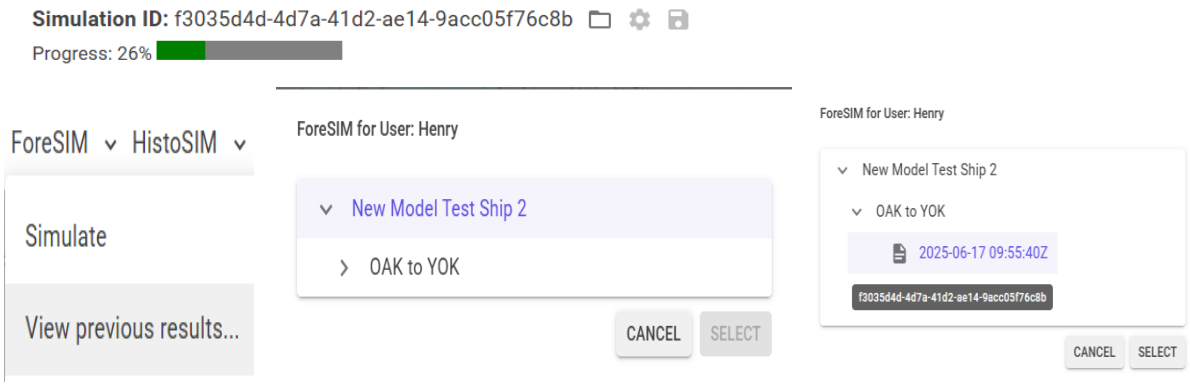


Figure 7. Retrieving previous simulated voyages.

Clicking on HistoSIM allows user to simulate voyages using archived data to generate monthly statistics beyond the forecast horizon in the desired month. The idea is to simulate many voyages with different starting times to quantify the uncertainties of simulated results in that month for planning future voyages.

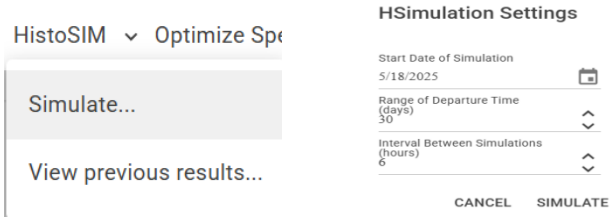
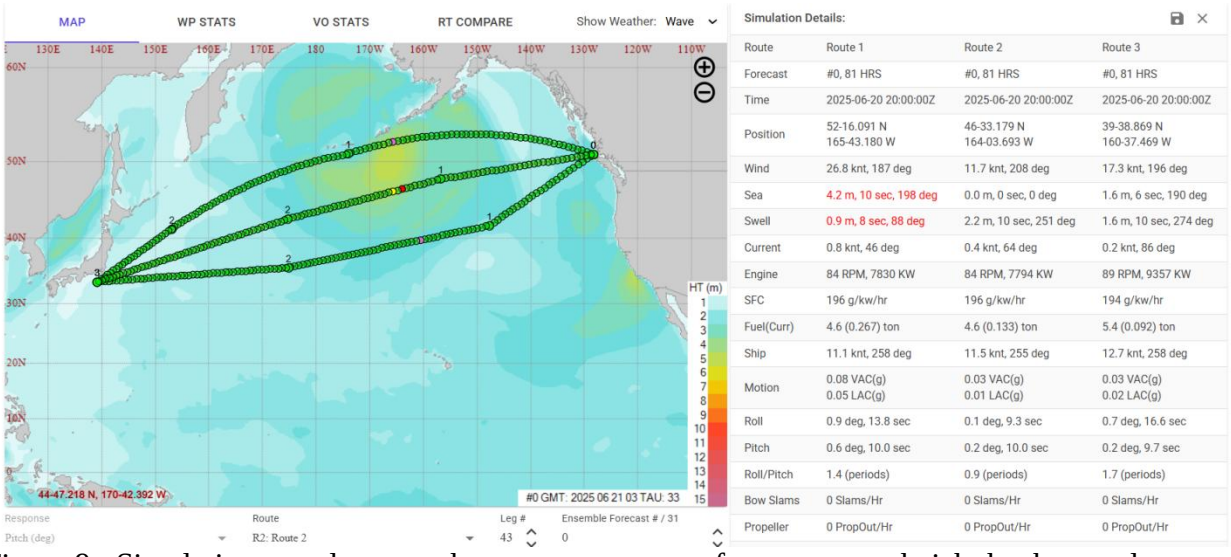


Figure 8. Setting up HistoSIM to generate monthly statistics for planning future voyages

Comparing Simulation Results

After the simulation has completed and results are transmitted to the user, the user will be able to try many what if scenarios expressed in terms of expected number of hours exceeding the specified ship motion thresholds as shown in Figure 9. The basis of the derivation is based on Linear Ship Motion and probability of threshold crossing from random vibration theory.

Segments on the route would change to Red when the simulated threshold limits are exceeded for the leg. Click and change the response threshold limits will also change the statistics on the expected hours of exceeding the thresholds to give a relative safety level on the three potential routes.



Route	Route 1	Route 2	Route 3
Forecast	#0, 81 HRS	#0, 81 HRS	#0, 81 HRS
Time	2025-06-20 20:00:00Z	2025-06-20 20:00:00Z	2025-06-20 20:00:00Z
Position	52-16.091 N 165-43.180 W	46-33.179 N 164-03.693 W	39-38.869 N 160-37.469 W
Wind	26.8 knt, 187 deg	11.7 knt, 208 deg	17.3 knt, 196 deg
Sea	4.2 m, 10 sec, 198 deg	0.0 m, 0 sec, 0 deg	1.6 m, 6 sec, 190 deg
Swell	0.9 m, 8 sec, 88 deg	2.2 m, 10 sec, 251 deg	1.6 m, 10 sec, 274 deg
Current	0.8 knt, 46 deg	0.4 knt, 64 deg	0.2 knt, 86 deg
Engine	84 RPM, 7830 KW	84 RPM, 7794 KW	89 RPM, 9357 KW
SFC	196 g/kw/hr	196 g/kw/hr	194 g/kw/hr
Fuel(Curr)	4.6 (0.267) ton	4.6 (0.133) ton	5.4 (0.092) ton
Ship	11.1 knt, 258 deg	11.5 knt, 255 deg	12.7 knt, 258 deg
Motion	0.08 VAC(g) 0.05 LAC(g)	0.03 VAC(g) 0.01 LAC(g)	0.03 VAC(g) 0.02 LAC(g)
Roll	0.9 deg, 13.8 sec	0.1 deg, 9.3 sec	0.7 deg, 16.6 sec
Pitch	0.6 deg, 10.0 sec	0.2 deg, 10.0 sec	0.2 deg, 9.7 sec
Roll/Pitch	1.4 (periods)	0.9 (periods)	1.7 (periods)
Bow Slams	0 Slams/Hr	0 Slams/Hr	0 Slams/Hr
Propeller	0 PropOut/Hr	0 PropOut/Hr	0 PropOut/Hr

Figure 9. Simulations results on each route segments on forecast wave height background

Notice also that the roll and pitch predictions include respective periods. Parametric roll may occur when period of roll is about twice as the pitch period for vessels with large bow/stern flares. The user can also quickly step through all legs and 31 forecasts as shown at the bottom of screen in Figure 9 to see where along the route safety limits are exceeded and how uncertainties of the forecast affect the responses.

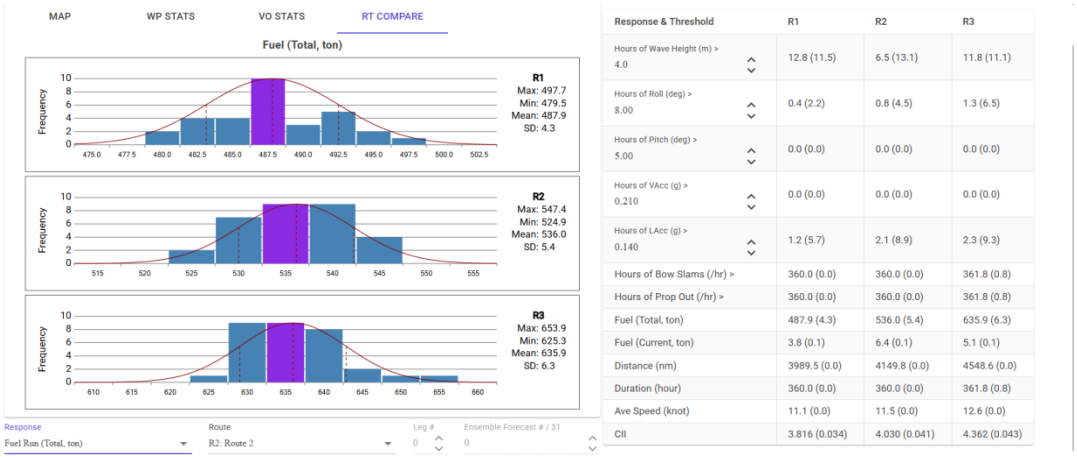
Clicking on WP STATS will show the simulated results of all 31 forecasts compiled in Series and Histogram format with Max/Min and Mean/Std Deviation values. Figure 10 shows a comparison the Sig Wave height at the middle of the voyage (81 Hr forecast) versus later at (256 Hr Forecast) on Route 2. Noticed the change in standard deviation (uncertainties) on the wave forecast along this Route. (The official forecast is shown in Purple color)

Figure 10. Histograms of wave height forecast from 31 members on different horizon (Tau)

Clicking on VO STATS shows plots of Voyage Statistics cumulated for the selected routes and response threshold instead of statistics on a particular Waypoint segment. Figure 11 shows a more insightful display of Series and Histogram of number of hours that Roll angle exceeded 8 degrees along Route 2 and the predicted Fuel consumption for Route 1 (R1)

Figure 11. Voyage Statistics on Roll response and Fuel Consumption for the selected Route.

Clicking on RT COMPARE allows user to compare various key performance metric of each route. Figure 12 show the comparison of predicted fuel consumption of three routes. Together with other metrics, user can select the best route taking into considerations of forecast uncertainties and safety measures. These metrics give the user an indication of the variability (measured by mean and standard deviation) of various route options. For example, R1 (the northern route) seems to be the best option consuming least fuel with less distance and less uncertainty. The forecast wave heights and roll response would not affect the safety while arriving at approximately the same time.



Response & Threshold	R1	R2	R3
Hours of Wave Height (m) > 4.0	12.8 (11.5)	6.5 (13.1)	11.8 (11.1)
Hours of Roll (deg) > 8.00	0.4 (2.2)	0.8 (4.5)	1.3 (6.5)
Hours of Pitch (deg) > 5.00	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Hours of VAcc (g) > 0.210	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Hours of LAcc (g) > 0.140	1.2 (5.7)	2.1 (8.9)	2.3 (9.3)
Hours of Bow Slams (/hr) >	360.0 (0.0)	360.0 (0.0)	361.8 (0.8)
Hours of Prop Out (/hr) >	360.0 (0.0)	360.0 (0.0)	361.8 (0.8)
Fuel (Total, ton)	487.9 (4.3)	536.0 (5.4)	635.9 (6.3)
Fuel (Current, ton)	3.8 (0.1)	6.4 (0.1)	5.1 (0.1)
Distance (nm)	3989.5 (0.0)	4149.8 (0.0)	4548.6 (0.0)
Duration (hour)	360.0 (0.0)	360.0 (0.0)	361.8 (0.8)
Ave Speed (knot)	11.1 (0.0)	11.5 (0.0)	12.6 (0.0)
CII	3.816 (0.034)	4.030 (0.041)	4.362 (0.043)

Figure 12. Route COMPARE statistics on key voyage metrics

Creating a grid to find Optimized Route using Dynamic Programming

Simulation of user created or imported routes allows user to select desired route based on voyage statistics including forecast uncertainties. But is there a better route with associated speed profile will minimize the fuel consumption without violating the safety constraints while still arrive on time? Clicking on Optimize Route will allow user to create a grid within which the "Optimum" route can be found after systematically evaluating thousands of route and speed options.

To create a grid, user can start by drag and drop waypoints of the original route to form an upper and lower bound.

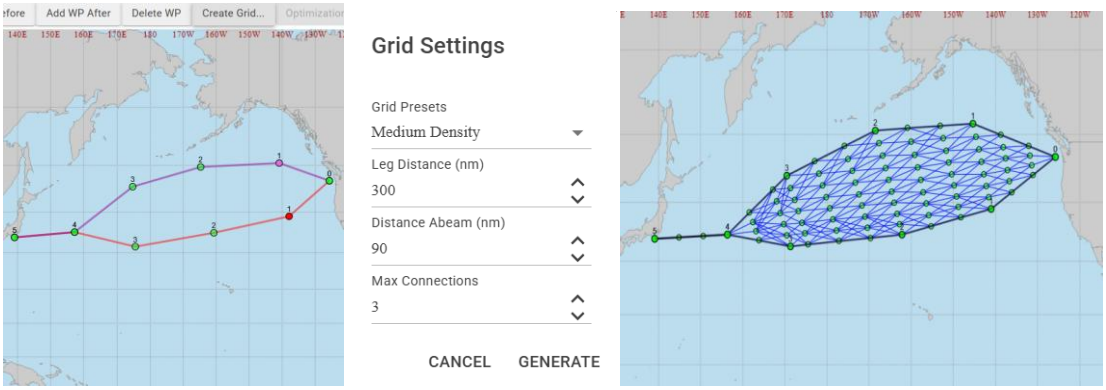


Figure 13. After creating upper and lower bounds, a grid can be created according to the settings

Dynamic Programming is a well know optimization algorithm which systematically evaluates route options both in lat/lon and time to arrive at the destination. Most importantly, AIVOS provides solutions over a range of arrival times around the desired ETA. User can trade-off between earlier or later arrival time with respective fuel cost, Time Chart Equivalent cost as well as GHG and CII.

Figure 14 shows the optimum route for a range of arrival times. User can click on the bar chart to select earlier or later than scheduled arrival time and see the difference in the voyage metrics.

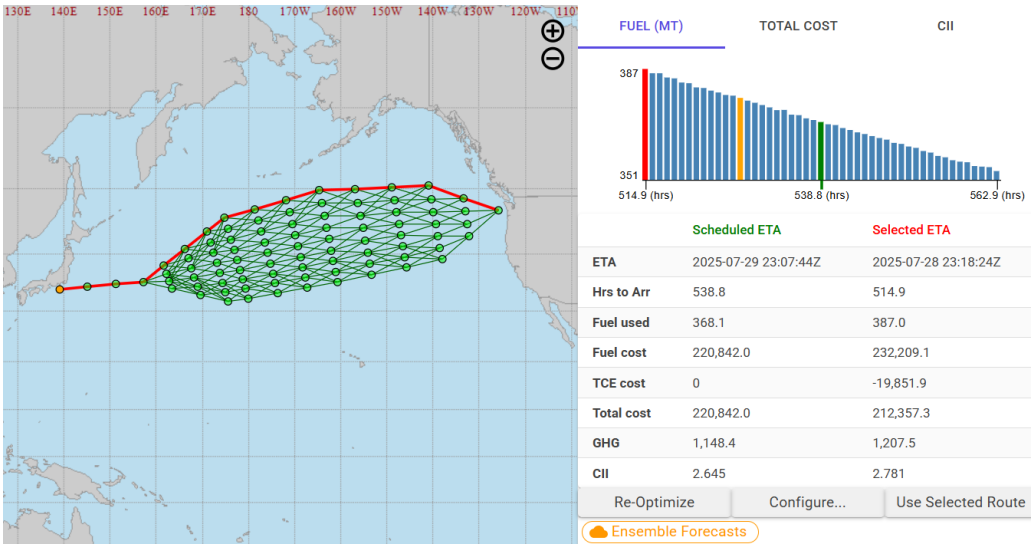


Figure 14. Clicking on the bar chart to compare Selected versus Scheduled arrival times.

Clicking on Use Selected Route will trace the optimum route for the desired ETA. User can then re-Simulate the original and the optimized route. Figure 15 shows the comparison in Fuel consumption for both routes with the same ETA. Notice that the optimized route (R2) saved about 7.4% of fuel consumption compared with the original route (R1).

Such savings can be higher or lower depending on the uncertainties from weather forecast, ship performance models and many other practical factors. AIVOS is a decision support tool for users to improve voyage safety, efficiency and reduce carbon footprints every voyage.

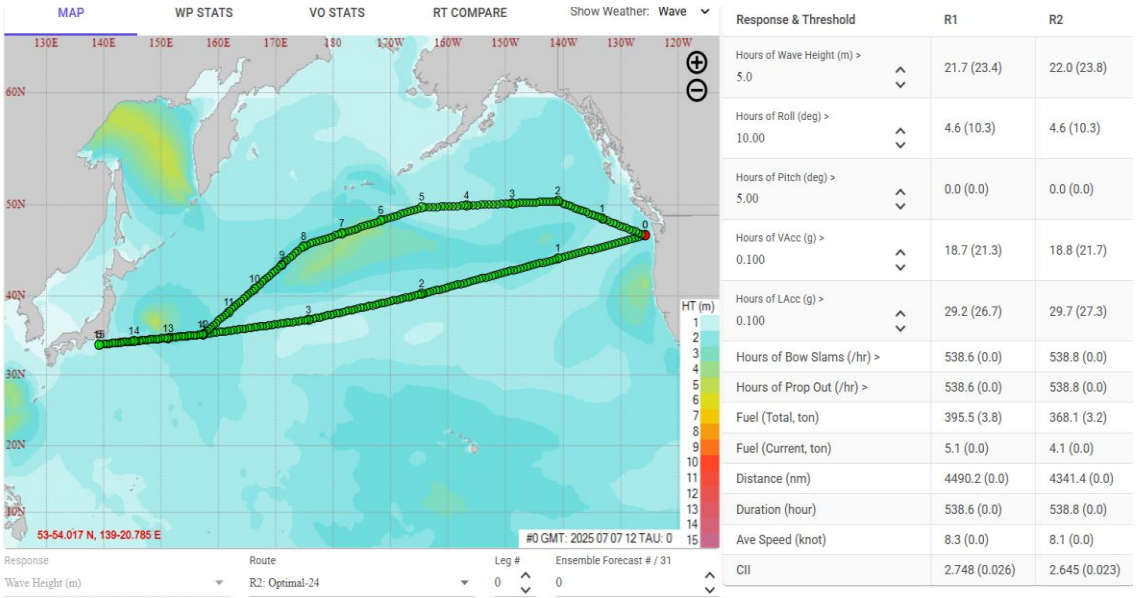


Figure 15. Comparison of the original versus optimized routes with the same ETA

Risk based Voyage Planning

Other Applications:

- **Performance evaluation for chartering**
- **Performance Monitoring**