Roads of the Sea

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Introduction

Maritime transport accounts for over 90% of global trade, yet vessel routing still presents significant safety and efficiency challenges. Groundings, collisions, and inefficient navigation can result in environmental damage, financial loss, and operational delays. The Roads of the Sea project aims to enhance maritime decision-making through two systems:

- Route Suggestion System- Generates optimal and alternative routes between ports based on vessel characteristics.
- Route Prediction System- Predicts the likely route a vessel will take based on trajectory data and vessel attributes.

Together, these systems leverage historical AIS and trajectory data to improve maritime safety, efficiency, and situational awareness.

Requirements

Functional Requirements

- Produce an optimal route and other potential routes for a given vessel.
- Filter possible routes based on vessel characteristics.
- Provide predictions for the top possible routes a vessel may take.
- Filter out impossible routes for the vessel.
- Interface which allows the user to provide port, trajectory, and vessel information.
- Output the suggestion and prediction maps when needed.

Non-Functional Requirements

- The User Interface should be intuitive and easy to use.
- Stable system that produces reliable results.
- Maintainable codebase.
- Results can be easily understood.
- Results are generated in a timely manner.

Data

The system utilizes maritime voyage and vessel data derived from historical AIS-based ship movement records. This provides voyage data and statistics such as vessel types, width, and draft.

Ports and individual voyages are visualized and explored in GIS, and port-to-port trajectory shapefiles are cleaned and created using python scripts from previous iterations of Roads of the Sea. The generated trajectories are then stored in a PostgreSQL databse. To seamlessly filter trajectories for suggestion, the data collection strategy was improved upon in order to get ship type specific data.

Trajectory data is converted into directed graph structures where:

- Nodes represent intersections or turning points
- Edges represent navigable waterways

Route Suggestion

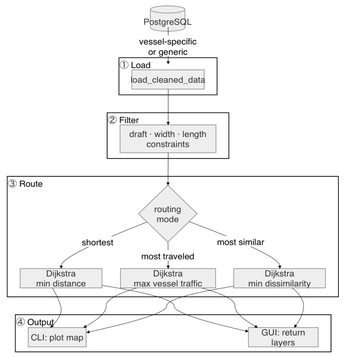

Image #1 Suggestion Algorithm Flowchart

- Port-to-port trajectory shapefiles are converted into a directed graph. Nodes = Intersections, Edges = Waterway segments
- Virtual sources and sinks to support multiple and start and end trajectories
- The network is filtered based on vessel characteristics: maximum draft, maximum width, maximum length, and ship type
- Dijkstra's algorithm computes the shortest route, most traveled route, or most similar vessels route
- Alternative viable routes are provided for flexibility
- Output is visualized on a map with the shortest path highlighted

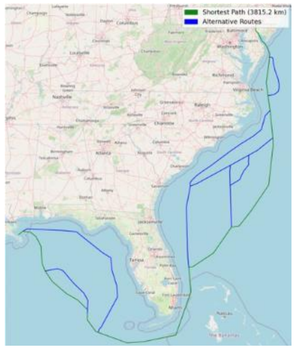

Image #2 Route Suggestion Map

Route Prediction

The purpose of the Route Prediction System is to provide the user with a similar path based on a given vessel's characteristics. This will help reduce vessel collisions by giving a vessel insight as to what other vessels are going to do.

This is represented by using a Similarity Algorithm that takes the trajectory and vessel characteristics and compares it with the stored network. Then it takes the three lowest valid similarity scores and outputs in the GUI.

The extension algorithm works by generating a ray between the last and second to last points on the input trajectory. This calculates the direct ion the vessel is traveling. Once the direction is calculated, the algorithm will extend from the last point to the nearest position in the baseline trajectory

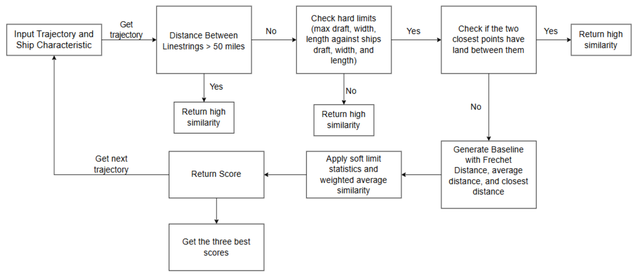

Image #3 Similarity Algorithm Flow Chart

User Interface

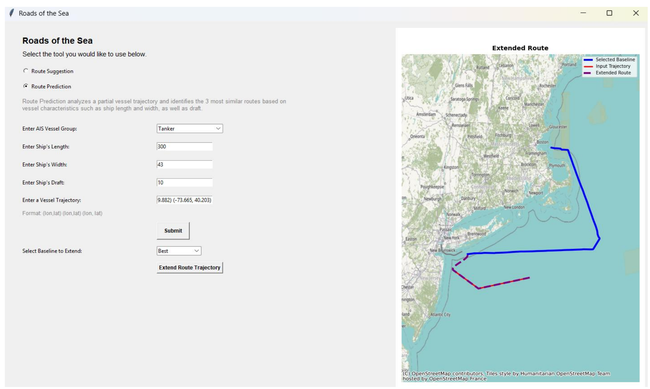

Image #4: UI after running similarity and extension algorithms

- The user interface is a desktop application that allows users to select between using Route Prediction or Route Suggestion
- Input boxes collect vessel and route data to fulfill the requirements of the selected algorithm.
- The UI calls the correct algorithm and displays the map output given
- Following an output from Route Prediction, the UI allows users to extend the input trajectory to a predicted trajectory.

Implementation

- The user interface is a simple desktop application created using Python (Tkinter) and Geospatial visualization tools
- Geospatial visualizations are powered by GeoPandas, Shapely, Matplotlib, Cartopy and Contextily
- Numpy was used for mathematical computations
- Unit testing with pytest to ensure code functionality
- PostgreSQL database for storing routes and trajectories
- SQLAlchmey for interacting with the database in Python

Testing

Roads of The Sea completed algorithms successfully generate feasible, constraint-aware outputs to their respective suggestion, prediction, and extension sections.

Tests verified the correctness of route geometry by validating latitude and longitude values across all generated trajectories. They also evaluated route feasibility by ensuring suggested and predicted paths avoid land masses and restricted areas.
Functional testing involved comparing shortest path outputs against known maritime routes to confirm reasonable trajectory length and structure. Additionally, consistency and stability of each algorithm was assessed by testing on multiple vessel types and input scenarios.

Conclusions

The Roads of the Sea project successfully presents a trajectory-based route prediction and suggestion system for maritime navigation. Key contributions include a practical proof-of-concept with interactive visual outputs and robust algorithms for route suggestion and prediction.

Future Improvements:

- Additional GUI improvements for appearance and usability
- Incorporate probability metrics to quantify the likelihood of predicted routes.
- Improve trajectory cleaning and generation to reduce noise in data.
- Allow users to generate routes based on vessels with the highest similarity to their own
- Scaling the system to larger geographic regions

This project lays the groundwork for more advanced maritime routing and predictive navigation systems, illustrating how data-driven systems can enhance safety, efficiency, and situational awareness.

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Abstract

The 2025-2026 Roads of the Sea development project is a route suggestion and prediction system for maritime travel. The purpose of these two systems is to take existing maritime route data to help generate optimal route suggestions for vessels and to predict the routes of other vessels given specific characteristics.

The route suggestion system converts port-to-port trajectory shapefiles into directed graph structures, where vessel constraints of length, width, draft, and ship type are applied for optimal and safe route suggestions. Dijkstra's algorithm is then used to compute the shortest or most traveled routes between ports.

The route prediction system provides the likelihood that a given vessel will take a certain path. The similarity algorithm uses a baseline similarity, which is computed as the average of the Fréchet distance and the distance between the two closest points on the trajectories. Additional multipliers are then applied to this baseline to weight the comparison, helping ensure that the predicted path closely resembles the typical route taken by similar vessels.

Together, these systems work in a centralized graphical user interface that allows users to input vessel and route information, validate parameters, and visualize outputs through dynamic map displays.