Development of a versatile and shortest path algorithm for the optimal ship routing

ARTIFICIAL INTELLIGENCE (BCSE306L)

PROJECT DOCUMENTATION

Development of a versatile and shortest path algorithm for the optimal ship routing

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Abstract

Title: ***Development of a Versatile and Shortest Path Algorithm for Optimal Ship Routing***

In the global maritime industry, optimizing ship routes is crucial for reducing operational costs, improving fuel efficiency, and enhancing safety at sea. This project focuses on the development of a versatile and intelligent shortest path algorithm tailored specifically for optimal ship routing. By integrating graph theory with real-time environmental data such as weather conditions, wave heights, and port congestion, the system dynamically identifies and evaluates multiple feasible routes between two ports.

The solution uses a graph-based approach to model global shipping routes and leverages APIs like OpenWeatherMap and wave monitoring datasets to incorporate real-time hazards and constraints. Fuel consumption estimates are derived using historical fuel efficiency datasets combined with predictive fuel pricing to calculate trip expenses accurately. The system also accounts for halt times, maintenance risks, and weather-induced delays, making it robust and adaptable to real-world maritime challenges.

An AI-augmented decision-making module suggests the best route by comparing fuel cost, estimated duration, environmental risks, and safety factors. An interactive map visualization enhances user interpretation, providing clear insights into the chosen path and alternatives. This approach empowers shipping companies to make smarter, data-driven decisions, ultimately contributing to greener, safer, and more economical maritime operations.

Introduction

The maritime industry plays a vital role in global trade, accounting for the transportation of over 80% of the world's goods. With increasing fuel costs, stricter environmental regulations, and the growing need for efficiency, optimizing ship routing has become more important than ever. Traditional routing methods often rely on static maps and generalized assumptions, which do not consider real-time maritime conditions such as weather patterns, port congestion, or wave dynamics.

This project addresses these limitations by developing a versatile and intelligent shortest path algorithm specifically designed for optimal ship routing. Unlike conventional pathfinding solutions, this approach dynamically adapts to real-world maritime data by integrating multiple data sources—including real-time weather forecasts, fuel prices, wave height information, and port conditions—into a graph-based routing framework.

Using graph theory, each port is treated as a node and every route as an edge weighted by distance, cost, or risk factors. The system calculates multiple optimal routes based on different criteria such as minimal fuel consumption, shortest time, or lowest overall cost. Moreover, it incorporates predictive analytics to estimate future fuel prices and delays, enhancing its decision-making capability.

By combining real-time APIs, historical data, and AI-enhanced optimization techniques, this system provides a practical and intelligent solution for modern ship routing challenges. The final output includes cost breakdowns, environmental risks, and precautionary measures, along with an interactive map for better visualization. This project aims to contribute to more sustainable, efficient, and safer maritime navigation.

Proposed Work

The proposed system is designed to develop a robust, data-driven, and intelligent ship routing algorithm that identifies the most optimal route between two ports while considering multiple real-time and static parameters. The main focus is to minimize the total operational cost, travel time, and environmental risks while ensuring navigational safety and fuel efficiency.

The key components of the proposed work are outlined below:

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1. Graph-Based Route Modeling

- Construct a directed graph where each port is represented as a node and shipping routes are edges weighted by distance.
- Implement shortest path algorithms (e.g., Dijkstra's or A*) to identify feasible paths between the source and destination ports.

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2. Integration of Real-Time Environmental Data

- Use OpenWeatherMap API to fetch live weather conditions (temperature, wind speed).
- Retrieve sea-state information such as wave height and wave power from publicly available marine datasets.
- Analyze the effect of high winds or rough seas on route safety and delay prediction.

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3. Fuel Consumption & Cost Estimation

- Load fuel efficiency data based on ship type and fuel type from historical records.
- Fetch real-time fuel price using OilPriceAPI.
- Estimate fuel consumption and compute total fuel cost for each route based on distance and ship efficiency.

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4. Port Halt Time and Congestion Modeling

- Analyze port congestion using vessel count data from port records.
- Estimate halt cost and additional delays depending on congestion level (High/Medium/Low).

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5. Risk Analysis and Precaution Generation

- For each route, identify potential hazards such as:
    - High wind zones
    - Congested ports
    - Rough sea areas
- Generate route-specific precautionary advice based on the identified risks.

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6. Route Evaluation and Optimization

- Evaluate each route based on:
    - Total distance
    - Duration
    - Fuel cost
    - Halt charges
    - Risk severity
- Select the optimal route using a cost-benefit analysis approach.

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7. Visualization and Output Generation

- Present route summaries including distance, cost breakdown, delays, issues, and precautions.
- Generate an interactive map using Folium to visualize the best route.
- Display weather and wave data for all major ports along the path.

Implementation

The implementation of the proposed ship routing system involves the development of an end-to-end Python-based application that integrates multiple data sources, graph algorithms, and external APIs to deliver intelligent, real-time ship route optimization. The system has been modularized for better maintainability, scalability, and integration.

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1. Data Preprocessing

- Input datasets include:
  - enhanced_routes.csv: Defines source–destination port pairs and distances.
  - enhanced_ship_fuel_efficiency.csv: Contains fuel consumption rates by ship and fuel type.
  - enhanced_Port_Data.csv: Includes port names and vessel congestion levels.
  - enhanced_download-csv-1.csv: Includes wave height and wave power per port.
- All data is loaded using pandas, cleaned, and merged as required.

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2. Graph Construction for Route Optimization

- A directed graph is created using networkx, where each edge represents a shipping route and is weighted by distance.
- Shortest path algorithms such as Dijkstra's and A* are used to generate multiple route options between the user-defined source and destination ports.

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3. API Integration

- **OpenWeatherMap API**: Fetches live temperature and wind speed for each port along the route based on latitude and longitude.
- **OilPrice API**: Fetches the current global fuel price per liter.
- **Geopy (Nominatim)**: Retrieves geolocation (lat/lon) of ports for weather lookup and map visualization.
- API calls are rate-limited and optimized using caching techniques to avoid redundant requests.

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4. Fuel Cost & Halt Cost Estimation

- For each route:
  - Distance is multiplied with ship-specific fuel consumption rate and real-time fuel price.
  - Halt charges are computed based on port congestion level (Low/Medium/High) from port data.

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5. Environmental Risk Assessment

- Wave height and wind speed are analyzed to flag risky segments.
- Ports with wind speed > 30 km/h or wave height > 3.5 m are marked as potential risk zones.
- Corresponding precautions are recommended, such as reducing speed or rerouting.

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6. Output Generation

- Each route is evaluated on:
  - Total distance (km)
  - Duration (based on average ship speed)
  - Fuel cost (USD)
  - Halt charges (USD)

- Issues and Precautions (textual)

- The most cost-effective and safest route is selected.

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7. Interactive Map Visualization

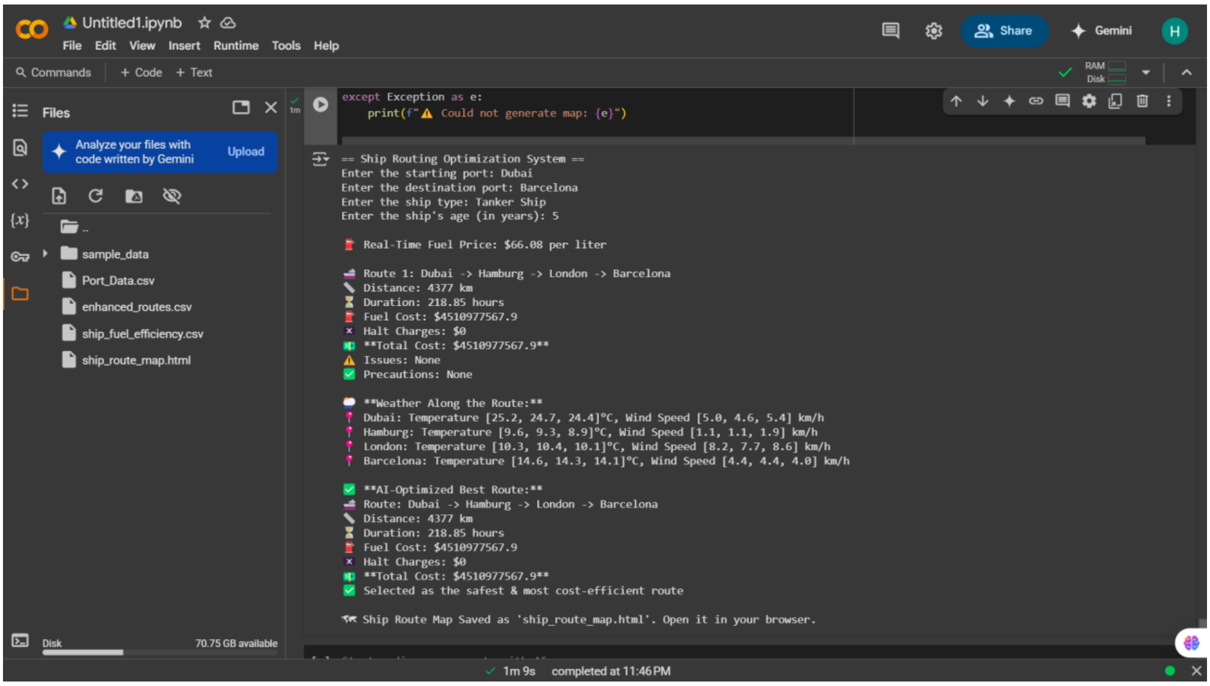
- An interactive map is created using the folium library.
- Port locations are marked, and the selected route is drawn as a polyline.
- The map is saved as an HTML file (optimized_ship_route_openweather.html) and can be opened in any web browser.

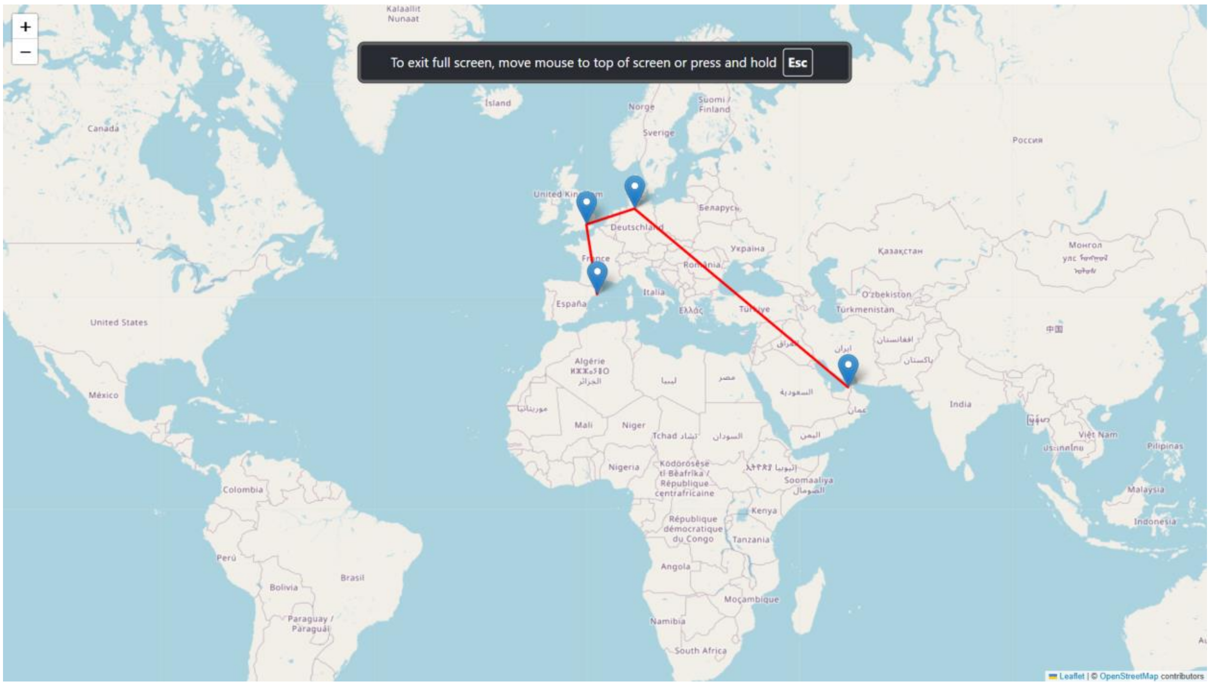
Tools & Technologies Used

Component	Tool/Library
Programming Language	Python
Graph Optimization	networkx
Data Handling	pandas
APIs	OpenWeatherMap, OilPriceAPI, Nominatim
Map Visualization	folium
Geolocation	geopy

This implementation ensures that ship routing decisions are not only based on shortest distance but also consider real-world operational variables like fuel price, congestion, wave height, and weather conditions — resulting in an intelligent and optimized routing system.

OUTPUT:


Untitled1.ipynb
File Edit View Insert Runtime Tools Help
Share
Gemini
Commands
+ Code + Text
Files
Analyze your files with code written by Gemini
Upload
sample_data
Port_Data.csv
enhanced_routes.csv
ship_fuel_efficiency.csv
ship_route_map.html
except Exception as e:
print(f"⚠ Could not generate map: {e}")
== Ship Routing Optimization System ==
Enter the starting port: Dubai
Enter the destination port: Barcelona
Enter the ship type: Tanker Ship
Enter the ship's age (in years): 5
Real-Time Fuel Price: $66.08 per liter
Route 1: Dubai -> Hamburg -> London -> Barcelona
Distance: 4377 km
Duration: 218.85 hours
Fuel Cost: $4510977567.9
Halt Charges: $0
Total Cost: $4510977567.9
Issues: None
Precautions: None
Weather Along the Route:
Dubai: Temperature [25.2, 24.7, 24.4]°C, Wind Speed [5.0, 4.6, 5.4] km/h
Hamburg: Temperature [9.6, 9.3, 8.9]°C, Wind Speed [1.1, 1.1, 1.9] km/h
London: Temperature [10.3, 10.4, 10.1]°C, Wind Speed [8.2, 7.7, 8.6] km/h
Barcelona: Temperature [14.6, 14.3, 14.1]°C, Wind Speed [4.4, 4.4, 4.0] km/h
AI-Optimized Best Route:
Route: Dubai -> Hamburg -> London -> Barcelona
Distance: 4377 km
Duration: 218.85 hours
Fuel Cost: $4510977567.9
Halt Charges: $0
Total Cost: $4510977567.9
Selected as the safest & most cost-efficient route
Ship Route Map Saved as 'ship_route_map.html'. Open it in your browser.
Disk
70.75 GB available
1m 9s completed at 11:46 PM


To exit full screen, move mouse to top of screen or press and hold Esc
Leaflet | © OpenStreetMap contributors

Conclusion

The maritime sector faces growing challenges in navigating complex global shipping networks while minimizing costs, improving fuel efficiency, and enhancing safety. This project successfully presents the **development of a versatile and shortest path algorithm** tailored for optimal ship routing by integrating graph theory with real-time environmental and operational data.

By constructing a directed graph of global shipping routes and applying advanced pathfinding algorithms, the system efficiently determines multiple route options between any two ports. The integration of live weather data, wave conditions, port congestion levels, and real-time fuel prices adds a dynamic, real-world dimension to route planning that is often missing in traditional systems.

The intelligent analysis and decision-making capability of the model allow it to evaluate and recommend the most cost-effective and safest route. It also considers risk factors such as high wind zones and rough seas, and provides corresponding precautionary measures, ensuring not just operational efficiency but also navigational safety.

An interactive map and structured output presentation further improve the usability and interpretability of the results, making the system practical for real-world maritime logistics applications.

In conclusion, this system offers a **comprehensive, data-driven, and adaptive solution** for optimal ship routing, with the potential to significantly enhance fuel economy, reduce travel time, and improve overall maritime operations.