PREDICTIVE MONITORING SYSTEM FOR COAL DELIVERY VESSEL

PROJECT REPORT

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JURUSAN REKAYASA DATA DAN BISNIS INTELIJENSIA

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1. Introduction

1.1. Background

PT PT Bahtera Adhiguna (PT. BAg) is a national shipping company and a subsidiary of PT PLN (Persero) through PLN Energi Primer Indonesia, which operates in the field of coal and primary energy transportation to support the electricity supply of PT PLN and its partners. Up to 40% of the cost in PT BAg is used for fuel consumption for 16 vessels. Currently, the vessel utilizes a combination of manual and digital fuel measurement systems. As is condition system is a software-as-a-service (SaaS) combined with Satellite data subscription using Iridium Satellite, which makes PT BAg reliant on a 3rd party system. The mixed system of measurement methods imposes limitations on data accuracy, speed, and cost-effectiveness.

1.2. Problem Statement

The Project Addresses this Challenge

- Around 40% PT Bag cost spent on Fuel for ship, currently monitoring the fuel usage in the ship using manual system, record on ship log
- Ship Arrival to customer also one of the key performance measurements. Delay can cause penalty
- Predicting both fuel usage and ship arrival is important, but takes time since it should read and evaluated from ship log
- Delayed Reporting happens, since using ship log sent to headquarter

1.3. Objectives

The Business Objective is to improve vessel operational efficiency by leveraging data -driven insights.

Technical Objectives is the change from the current state (As-Is) to the desired state (To-Be) is defined as follows:

- Automatic Measurement of fuel inventory in the tank.
- Automatic Measurement of fuel consumption in the Auxiliary Engine (AE) and Main Engine (ME).
- Integration of manual measurement readings into the Fuel Management System (FMS) application.
- Predictive fuel consumption and Estimated Time of Arrival (ETA).

1.4. Success Criteria

The Project Considered success following these criteria:

- Estimated Time Arrival Predicted in > 95% of time
- Real-time data latency < 1 minutes
- System uptime > 95%

- The Project Satisfy Audits findings

2. Project Management

2.1. Project Timeline

Sprint	Duration	Phase	Key Activities	PIC
1	W1-W2 Sept 2025	Initiation	Stakeholder Interviews	PNM, RWH
2	W3-W4 Sept 2025	Initiation	Requirements Gathering	PNM, RWH
3	W1-W2 Okt 2025	Analysis & Design	UML Diagram, Architecture Diagram, Database Schema	PNM, RWH, APS
4	W3-W4 Okt 2025	Analysis & Design	Backend API, MQTT setup, Database implementation	PNM, RWH, APS
5	W1-W2 Nov 2025	Development Sprint 1	Frontend	RWH, APS
6	W3-W4 Nov 2025	Development Sprint 2	Backend API	RWH, APS
7	W1-W2 Des 2025	Development Sprint 3	MQTT setup, Database Implementation	RWH, APS
	W3-W4 Des 2025	Holiday		
8	W1-W2 Jan 2026	Development Sprint 4	ML Service & Model Training	RWH, APS
9	W3-W4 Jan 2026	Testing & QA	Integration Testing, UAT, Performance Testing	PNM, RWH
10	W1-W2 Feb 2026	Deployment	Production Deployment	PNM, RWH

2.2. Project Person in Charge

Project Person in Charge:

- Angga Pratama Suryabrata (APS)
- Rina Widyasti Habibah (RWH)
- Putri Nur Meilisa (PNM)

2.3. Scope

A Software Development Project consist of

- Central Applications with deliverables in
- On ship Edge Gateway Implementations

- Machine learning model for Fuel usage prediction and ETA arrival

2.4. Business modelling

The Predictive Monitoring System for PT Bahtera Adiguna (Bag) are to track real-time 15 minutes interval Ship monitoring with considering operational parameter such as fuel consumption engine load, vessel speed, route and sea state.

Value Proposed by team are to provide actionable insights for Bag as ship Operators to optimize route planning and fuel cost. Ultimately improving profitability and sustainability. Using 2 predictive functions: Ship fuel consumptions and Estimated Time of Arrival. The project aiming to improve vessel operational efficiency by leveraging data-driven insights.

Business Model for this project are Business to business Application development project that consist of Developing Software and implementing IoT systems on ships.

2.5. Risk Register

Risk Category	**Risk Description**	**Probability**	**Impact**	**Mitigation Strategy**
Technical	LSTM model accuracy below target	Medium	High	Hyperparameter tuning as Supporting Service in Post Production
Technical	MQTT connectivity loss at sea	High	Medium	Local buffering, retry logic
Technical	Sensor calibration drift	Medium	Medium	Periodic Calibration schedule, redundant Sensors
Operational	User adoption resistance	Medium	High	Comprehensive training, change management program
Operational	Data Quality issues	High	High	Validation Rules, Anomaly Detections
Project	Timeline Delays	Medium	Medium	Prioritization
External	External Integrations (etc Weather API)	Low	Medium	Caching and choose Services with High Uptime SLA
Security	Unauthorized access	Low	High	Implement Tight Security Configurations (Authentication, Encryption) Implement Audit logging

2.6. Stakeholder Analysis

Stakeholder	Interest	Influence	Engagement Strategy	Communication Frequency
Planning Department (BAg HQ)	High	High	Maintain Close Relations	Bi weekly Report and Daily Communications
Ship Captains	High	medium	Request Feedback	Per -requested. Taking notes on feedback
Operational Department – Fleet Management (HQ)	High	High	Maintain Close Relations	Bi weekly Report and Daily Communications
IT Department (Project Team)	Medium	High	Maintain Close Relations	Bi weekly Report and Daily Communications
Regulatory Bodies	Low	Medium	Maintain Compliance	Per – needed basis
Board of Directors	High	High	Final Decision	Bi weekly Report

2.7. RACI Matrix

Activity / Role	Responsible (R)	Accountable (A)	Consulted (C)	Informed (I)
Project planning	Project Manager	Operational Department – Fleet Management (HQ)	Planning Department (Bag HQ), Ship Captains	All stakeholders
Needs analysis	Technical Team	Project Manager	Operational Department – Fleet Management (HQ), Ship Captains	All stakeholders
System / solution design	Technical Team	Project Manager	Operational Department – Fleet Management (HQ)	Board of Directors
Implementation	Technical Team	Project Manager	Operational Department – Fleet Management (HQ)	All stakeholders
Evaluation & reporting	Project Manager	Board of Directors	Operational Department – Fleet Management (HQ), Ship Captains	All stakeholders

3. Design

3.1. Core Features

a. Route Visualization

- Interactive Map
- Dual – Line Rendering
    - Solid green line: traversed path
    - Dotted gray line: remaining route
- Weather overlay: Real-time weather conditions along route

b. Real-Time Fuel Monitoring

- Dashboard: a Live Fuel level visualization for entire fleet
- Alerts: Threshold-based notifications for low fuel levels
- Historical Trends: 30 – day fuel consumptions patterns
- Sensor Health: Status monitoring for IoT Device (connected/disconnect/Unavailable)

c. ETA – Prediction (Supervised Machine Learning Based)

Input Features:

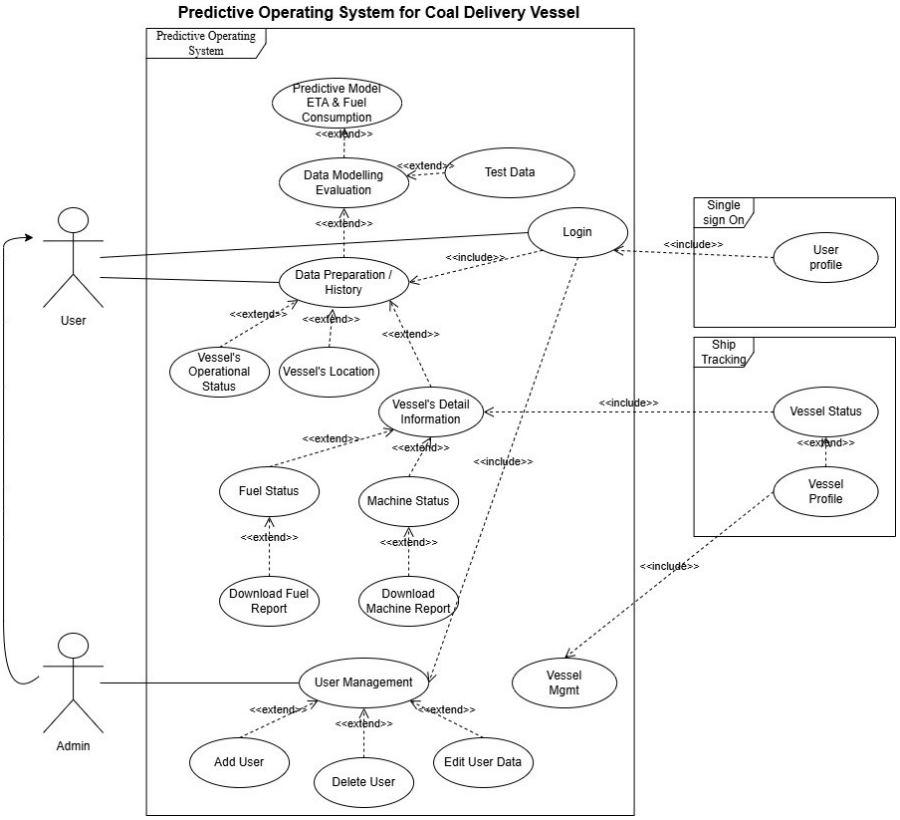
- Historical voyage data (AIS)
- Current Location & Speed
- Weather conditions along route
- Sea current data
- Vessel characteristic (draft, tonnage)

d. Model Architecture:

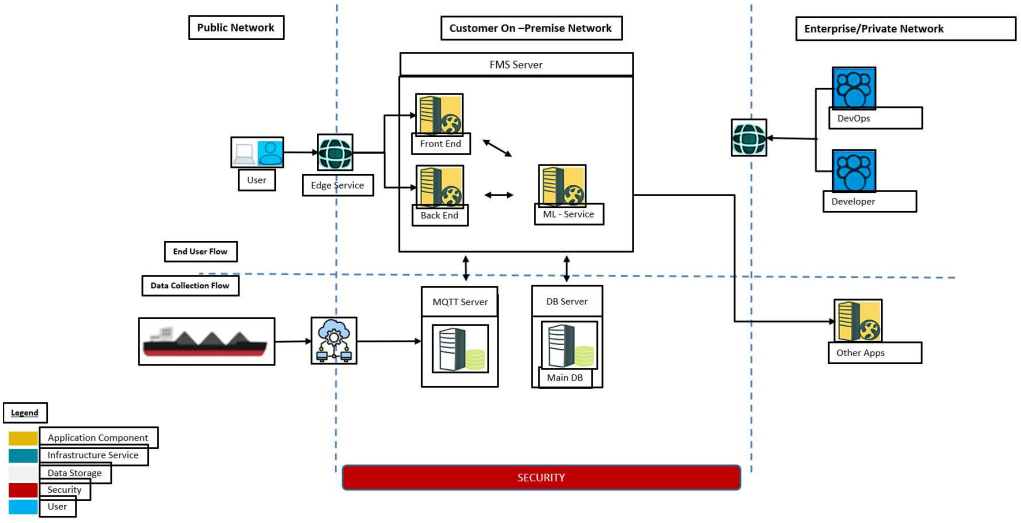
- Bi-directional LSTM with attention mechanism
- Input sequence length: 24 hours historical data
- Output: ETA + - 5 to 10 % minutes with 95% confidence interval

3.2. Diagram

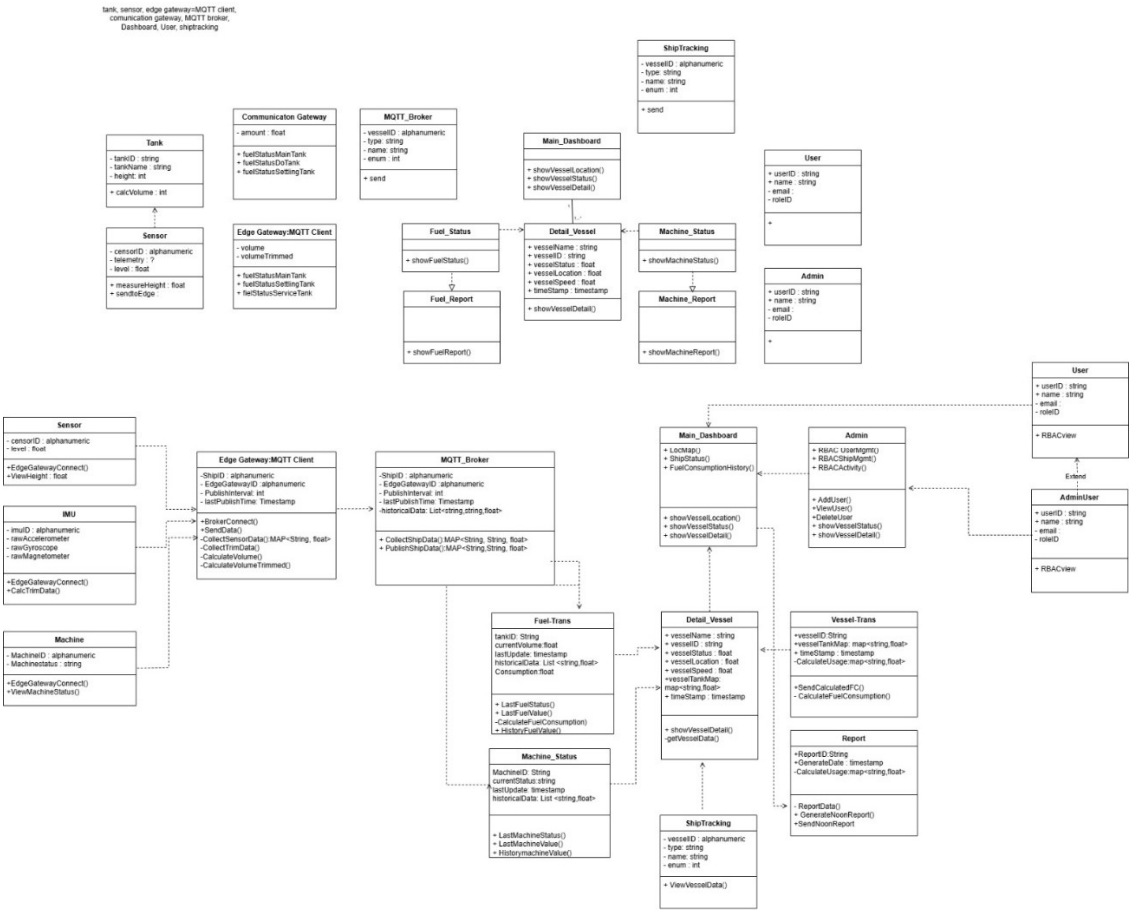
a. Use Case Diagram



b. System Architecture Diagram



c. Class Diagram



d. Sequence Diagram

- **ETA Prediction Flow (On Progress Research)**

  On Progress Research

- **Fuel Prediction Flow(On Progress Research)**

  On Progress Research

3.3. Technical Deliverables

- Frontend Application using Vue.js 3 + TypeScript + Tailwind CSS
- Backend API Go - RESTful architecture
- Machine Learning Service using Python + TensorFlow/Keras
- MQTT Infrastructure using Mosquitto broker + edge gateways
- Database Schema using PostgreSQL with TimescaleDB extension
- Infrastructure using Virtual Machine VMware and Kubernetes (On Premise Deployment
- API Documentation using OpenAPI/Swagger

3.4. Document Deliverables

- User Manual
- Technical Documentation

3.5. Software Function Deliverables

Priority	Module	Feature	Description	Deliverables
	Application > Central Application on Shipping Company Private Cloud with Public Access			
Must	Auth & RBAC	Login & Role-based Read-only	View access based on roles (NOC Operator, Fleet Manager, Auditor) with no write actions.	Concise User Manual
Must	UI Frame	UI Kit	Translate Figma to Usable UI (Button, Frame, Panel, Data List,)	Wireframes & Mockups
Must	Fleet Map	Fleet Map & Status	Vessel clustering, status colors (normal/low fuel/offline), search and filters.	View/Data Model
Must	Vessel Dashboard	Tank Cards	Height (mm), Volume (m^3), Capacity %, last update timestamp per tank.	Lightweight Design System
Must	Trends & History	24h/7d Charts	Zoom/pan with toggleable series (height/volume).	View/Data Model
Must	Alert Center	Alert History (View-only)	List & filter alerts by severity/type/time/vessel.	Wireframes & Mockups
Must	Export	Report Export	Export CSV/PDF for fleet/vessel snapshot over selected period.	Concise User Manual
Must	UI/Performance	Auto-Refresh & Loading Indicators	Default 15-second auto-refresh, manual refresh button, loading indicators.	Wireframes & Mockups
Should	Calibration Viewer	Calibration Curve Overlay (Read-only)	Show height→volume curve as a reference on the chart.	Lightweight Design System
Should	Geofence	Port/Route Overlay	Display geofences on the map (view-only).	UI & E2E Test Plan
Should	Analytics Widgets	Top-N Vessels	Widget for vessels with lowest fuel / most frequently offline.	Lightweight Design System
Should	Analytics	Speed Prediction Widget (Read-only)	Displays short-horizon speed forecast (e.g., next 2–6 hours) based on recent GPS time-series; UI consumes prediction API.	UI & E2E Test Plan
Could	UI Frame	Dark Mode / PWA	Dark theme and installable app (optional).	Lightweight Design System
	Ship > Tailored Configuration for Each Ship			
Must	AssetSensor	Asset Unique ID, List & Connection	Recognize Sensor and Unique ID Sensor, Data and Attribute	API Integration Spec (Read-only)

Must	AssetTank	Asset Unique ID, Tank Information	Tank ID and Tank VOlume Calculation	API Integration Spec (Read-only)
Must	VolCalc	Volume Calculation	Calculate Level Sensor to Volume Table to get Volume	API Integration Spec (Read-only)
Must	TrimCalc	TrimmedCalculation	Calculate Volume based on Ship Current Trim	API Integration Spec (Read-only)
Must	Payload	Payload send to Central System	Agreement to Central System for Payload	Concise User Manual
	Project			
	Weekly	**Weekly**	**Weekly**	
	Daily	**Daily**	**Daily**	
Must	Auth & RBAC	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	UI Frame	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Fleet Map	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Vessel Dashboard	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Trends & History	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Alert Center	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Export	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	UI/Performance	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Should	Calibration Viewer	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Should	Geofence	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Should	Analytics Widgets	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Should	Analytics	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan

Could	UI Frame	Positive & Negative Test	Automate Test Case and QA Using Positive and Negative Test for each Modul	UI & E2E Test Plan
Must	Auth & RBAC	Documentation	Write Documentation	UI & E2E Test Plan
Must	UI Frame	Documentation	Write Documentation	UI & E2E Test Plan
Must	Fleet Map	Documentation	Write Documentation	UI & E2E Test Plan
Must	Vessel Dashboard	Documentation	Write Documentation	UI & E2E Test Plan
Must	Trends & History	Documentation	Write Documentation	UI & E2E Test Plan
Must	Alert Center	Documentation	Write Documentation	UI & E2E Test Plan
Must	Export	Documentation	Write Documentation	UI & E2E Test Plan
Must	UI/Performance	Documentation	Write Documentation	UI & E2E Test Plan
Should	Calibration Viewer	Documentation	Write Documentation	UI & E2E Test Plan
Should	Geofence	Documentation	Write Documentation	UI & E2E Test Plan
Should	Analytics Widgets	Documentation	Write Documentation	UI & E2E Test Plan
Should	Analytics	Documentation	Write Documentation	UI & E2E Test Plan
Could	UI Frame	Documentation	Write Documentation	UI & E2E Test Plan

3.6. Wireframe

Current Wireframe concept for main page

3.7. Software Testing Strategies

1. Unit Tests Using Positive and Negative Case

- Backend using Go testing framework
- Frontend using Vitest + Vue Test Utils
- ML Service Using pytest + unittest
- Functional (Menu Test) Target :
  - Target Function:
  - Auth & RBAC
  - UI Frame
  - Fleet Map
  - Vessel Dashboard
  - Trends & History
  - Alert Center
  - Export
  - UI/Performance
  - Calibration Viewer
  - Geofence
  - Analytics Widgets
  - Analytics
  - UI Frame

2. Integration Tests

- API endpoint testing using (Postman/Newman)
- MQTT message flow validation using Wireshark
- Database transaction integrity
- ML model inference pipeline using pytest

3. Performance Tests

- Load testing: 100 concurrent users using jmeter
- Stress testing: MQTT message throughput (1000 msg/s) using jmeter
- ML inference latency: < 500ms p95*

4. User Acceptance Testing (UAT)

- Scopes: 2-week pilot with 2 vessels
- Captain feedback sessions
- Fleet manager approval checklist
- Functional (Menu Test) Target :
  - Target Function:
  - Auth & RBAC
  - UI Frame
  - Fleet Map
  - Vessel Dashboard
  - Trends & History
  - Alert Center
  - Export
  - UI/Performance
  - Calibration Viewer
  - Geofence
  - Analytics Widgets
  - Analytics
  - UI Frame

5. Security Testing

- Penetration testing (OWASP Top 10)
- API authentication/authorization
- Data encryption verification

4. Current State Development (Progress)

4.1. Project State

Sprint	Duration	Phase	Key Activities	PIC	Status
1	W1-W2 Sept 2025	Initiation	Stakeholder Interviews	PNM, RWH	Completed
2	W3-W4 Sept 2025	Initiation	Requirements Gathering	PNM, RWH	Completed
3	W1-W2 Okt 2025	Analysis & Design	UML Diagram, Architecture Diagram, Database Schema	PNM, RWH, APS	Completed
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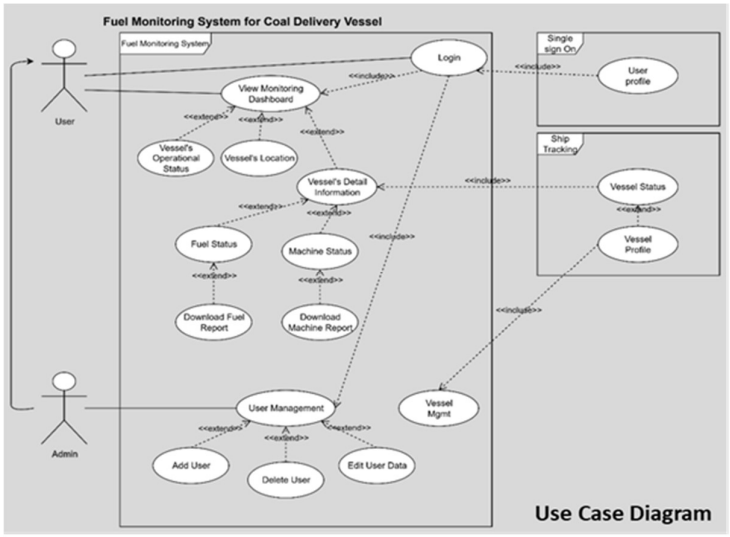
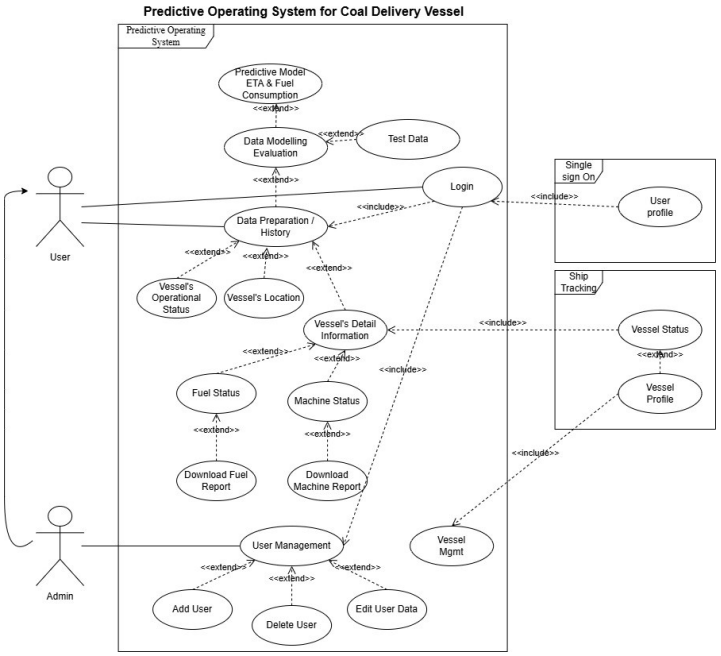
5	W1-W2 Nov 2025	Development Sprint 1	Frontend	RWH, APS	Completed
6	W3-W4 Nov 2025	Development Sprint 2	Backend API	RWH, APS	In Progress
7	W1-W2 Des 2025	Development Sprint 3	MQTT setup, Database Implementation	RWH, APS	Backlog
	W3-W4 Des 2025	Holiday			
8	W1-W2 Jan 2026	Development Sprint 4	ML Service & Model Training	RWH, APS	Backlog
9	W3-W4 Jan 2026	Testing & QA	Integration Testing, UAT, Performance Testing	PNM, RWH	Backlog
10	W1-W2 Feb 2026	Deployment	Production Deployment	PNM, RWH	Backlog

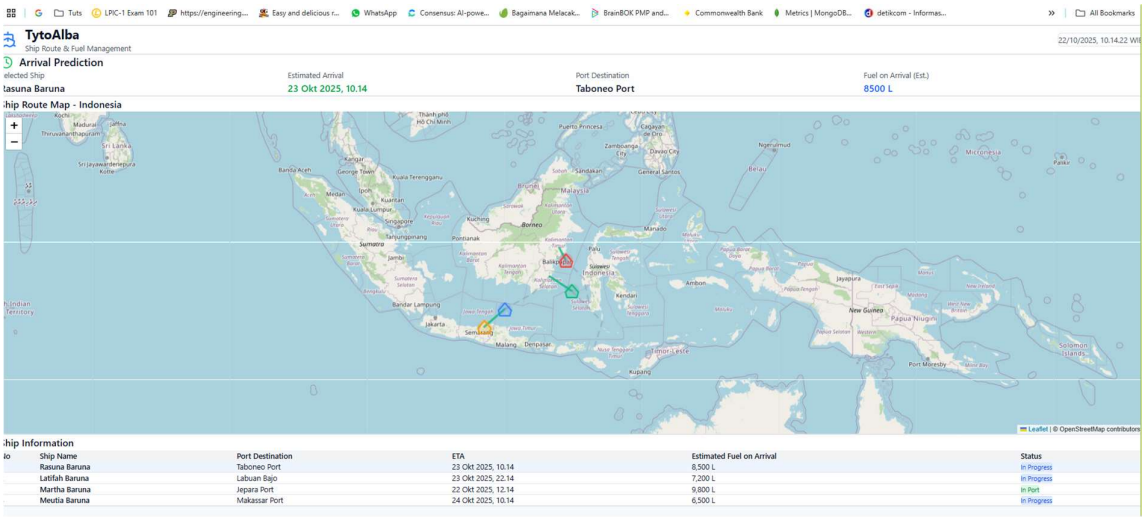
4.2. Issue list (Current Progress)

Current Issue on Development Sprint 2 are:

Issue	Action	Status
Additional feature Prediction	Update UML: initial diagram  Current Diagram needs additional Nodes for Ship Fuel Prediction and ship ETA  	Done

Need to Add Prediction Model	Create ML Service as node in system design using python technologies and LTSM Supervised learning. Expose API using fastAPI	On Progress
Using Random Forrest model as Supervised Learning model Prediction for Fuel and Arrival. Rejected by user	Research on LTSM model for Fuel Prediction and Arrival Prediction	On Progress
Ship route doesn't reflect to ship arrival. Only routes with strip line and ship symbol	Change Ship route visualization with: - Traverse line as green line. - estimated arrival line as dotted grey line	On Progress
Frontend to backend hasn't linked yet	Start develop backend service. create unit test case	Pending

4.3. Current Visualization



5. References

5.1. Research Papers

1. Abdi, A., & Amrit, C. (2024). Enhancing vessel arrival time prediction: A fusion-based deep learning approach. *Expert Systems with Applications*, *252*(PA), 123988. https://doi.org/10.1016/j.eswa.2024.123988
2. Zhang, M., Tsoulakos, N., Kujala, P., & Hirdaris, S. (2024). A deep learning method for the prediction of ship fuel consumption in real operational conditions. *Engineering Applications of Artificial Intelligence*, *130*(December 2023), 107425. https://doi.org/10.1016/j.engappai.2023.107425
3. Chen, Y., Huang, Z., & Feng, L. (2024). Research on Ship Main Engine Fuel Consumption Model With Data Integration and Noise Cleaning. IEEE Access, 12(October), 154546–154569. https://doi.org/10.1109/ACCESS.2024.3478783
4. Kim, S.; Kim, H.; Jeon, H. Development of a Simplified Performance Monitoring System for Small and Medium Sized Ships. J. Mar. Sci. Eng. 2023, 11, 1734. https://doi.org/10.3390/jmse11091734

5.2. Technical Documentation

- TensorFlow/Keras Documentation for Model building and training
- Vue.js 3 Composition API for Frontend reactive patterns
- Go HTTP Server Best Practices for Backend architecture
- MQTT Protocol Specification for IoT communication standards
- PostgreSQL TimescaleDB for Time-series database optimization

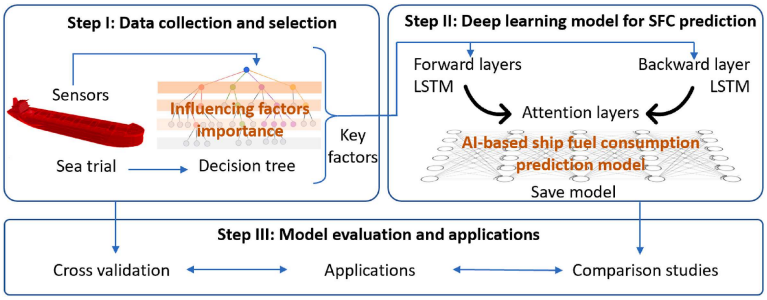
5.3. Industry Standards

- ISO 19848:2018. A Standard for Ships and marine technology. Mainly for shipboard machinery and equipment
- IEC 61162. Maritime navigation and radiocommunication equipment and systems
- IMO MEPC Guidelines. Fuel consumption reporting standards

Appendix 1 : Reference

1. Reference Architecture of Predictive ETA and Fuel Consumption

Abdi, A., & Amrit, C. (2024). Enhancing vessel arrival time prediction: A fusion-based deep learning approach. Expert Systems with Applications, 252(PA), 123988. https://doi.org/10.1016/j.eswa.2024.123988



Zhang, M., Tsoulakos, N., Kujala, P., & Hirdaris, S. (2024). A deep learning method for the prediction of ship fuel consumption in real operational conditions. *Engineering Applications of Artificial Intelligence*, *130*(December 2023), 107425. https://doi.org/10.1016/j.engappai.2023.107425

Appendix 2: Timeline

No	List	List Feature			Estimated Start Month : September 2025																	
					Sprint 1		Sprint 2		Sprint 3		Sprint 4		Sprint 5		Sprint 6		Sprint 7		Sprint 8		Sprint 9		Sprint 10	
					W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20
1	Business Modelling																							
		1.1	Business Modelling	P																				
				A																				
2	Requirements																							
		2.1	Feature Requirements	P																				
				A																				
		2.2	System Requirements	P																				
				A																				
3	Analysis & Design																							
		3.1	User & Feature Matrix	P																				
				A																				
		3.2	Data Table Design	P																				
				A																				
		3.3	User Interface (Prototyping)	P																				
				A																				
		3.4	Report Design	P																				
				A																				
4	Development																							
			Central Application System																					
		4.1	Login & Role-based Read-only	P																				

				A																				
		4.2	UI Kit	P																				
				A																				
		4.3	Fleet Map & Status	P																				
				A																				
		4.4	Tank Cards	P																				
				A																				
		4.5	24h/7d Charts	P																				
				A																				
		4.6	Alert History (View-only)	P																				
				A																				
		4.7	Report Export	P																				
				A																				
		4.8	Auto-Refresh & Loading Indicators	P																				
				A																				
		4.9	Calibration Curve Overlay (Read-only)	P																				
				A																				
		4.10	Port/Route Overlay	P																				
				A																				
		4.11	Top-N Vessels	P																				
				A																				
		4.12	Speed Prediction Widget (Read-only)	P																				
				A																				
		4.13	Dark Mode / PWA	P																				
				A																				

		4.14	API Integration	P																				
				A																				
			Ship System																					
		4.15	Asset Unique ID, List & Connection	P																				
				A																				
		4.16	Asset Unique ID, Tank Information	P																				
				A																				
		4.17	Volume Calculation	P																				
				A																				
		4.18	TrimmedCalculation	P																				
				A																				
		4.19	Payload	P																				
				A																				
5	Testing																							
		5.1	UAT Environment Preparation	P																				
				A																				
		5.2	UAT (User Acceptance Test)	P																				
				A																				
		5.3	Documentation	P																				
				A																				
6	Deployment																							
		6.1	Production Environment Preparation	P																				
				A																				
		6.2	Deploy to Production	P																				

				A																				
		6.3	Migration Data	P																				
				A																				
		6.4	Cut Off and Go-Live	P																				
				A																				
		6.5	Sign Off																					