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“Optimising Port Pilot Routes and Trips” (Challenge Code: #OC2-PA-C11)

Background

In every busy harbor, port pilots play an important role in the safe navigation of ships from the open ocean into the berths. Commercial ships are boarded by Port Pilots through small pilot boats, a physically strenuous and often dangerous process due to changing weather, strong currents, and low visibility.

However, poorly planned pilot trips frequently result in delays, operational disruptions, and unnecessary fuel consumption. Present-day port pilot operations are almost entirely manual and based on very loosely formulated schedules. Most communication is conducted on very basic VHF radio systems. This outdated system leads to operational inefficiencies, increased carbon emissions, delayed pilot assignments, and cascading impacts across port logistics.

A recent study by Wang et al. (2024) highlights the urgent need for integrated optimization in pilot and pilot carrier routing. Their research model, which accounts for service windows, synchronization constraints, and working durations, demonstrated significant improvements in port efficiency and timeliness when applied to congested maritime settings.

Similarly, research by Hematian, Audy and Rönnqvist (2025) discovered, in their study of the St. Lawrence River corridor, that actual-time performance metrics and equity issues for pilot dispatching reduced waiting times by 14% and improved workload allocation. These are signposting findings to underscore the call to move away from reactive, manual pilot scheduling practices.

The painful absence of real-time coordination solutions, weather-based planning, and automated scheduling within port pilot logistics provides a strong case for digital transformation. With the world's ports coming under greater pressure to be greener and more efficient, there has been a better time to fine-tune this critical port operation with technology.

This section defines pilot transfer system pain points and presents a digital solution designed to improve planning, communication, and safety in pilot operations.

Business Problem

Port pilotage currently relies on manual scheduling with minimal real-time visibility. Traditional communication methods amplify these inefficiencies, impacting the maritime ecosystem. The industry operates at a high-stakes level, where even minimal inefficiencies can result in catastrophe of logistical and financial consequences.

Current research by Wang et al. (2024) illustrates that current pilot and carrier routing procedures are not optimal, especially under congestion and environmental uncertainty. Their integrated model showed significant delay and pilotage cost reductions over conventional systems. Research on pilot dispatching in the St. Lawrence River by Hematian, Audy and Rönnqvist (2025) established that the application of fairness and time-oriented performance measures resulted in a reduction of 14% in waiting time and an improved workload balance, highlighting the ineffectiveness of manual dispatch models. This research affirms the urgent requirement for dynamic digital coordination tools.

As highlighted by Adib Ahasan (2024), modern pilot dispatch system significantly enhances ship scheduling accuracy and reduces turnaround times, making traditional practices increasingly outdated.

Problem Statement:

Current pilot service coordination systems are largely reactive in character and lack integration with real-time data such as weather, vessel ETAs, and resource availability. As a result, dispatching is irregularly varied, giving rise to safety hazards and ineffective resource usage.

Key Operational Pain Points:

•Manual Scheduling: Pilot assignments are often achieved by spreadsheets or basic systems, without dynamic reassignment when conditions alter.

• Lack of Incorporation of Real-Time Information: Weather and traffic data are not fed into scheduling software, making decisions lag what is happening in the real world.

• Poor Utilization of Resources: Pilots and tugboats are either underused or overworked, increasing operating costs or delays.

• Unnecessary Fuel Consumption: Inefficient routing and idle waiting result in excessive fuel consumption, making the process environmentally unsustainable.

• Connectivity Gaps: In using VHF radio communication, latency and confusion among ships, control centers, and pilots are created.

• Absence of automation: Legacy systems lack the capability of handling dynamic ports and cannot facilitate predictive operation.

• User Interface Problems: Existing tools cannot be utilized, especially by field users like pilots operating under time pressure.

Stakeholders and Users Affected:

• Port Pilots: Face safety risk from unpredictable scheduling and poor visibility into changes.

• Harbor Control Operators- Must have to make swift decisions using outdated hardware and limited operational knowledge.

• Shipping Lines and Port Authorities- Higher cost of overtimes and unexpected delays.

• Tugboat Service Providers- Misaligned experience operations, affecting docking efficiency.

As shown in research by Wang et al. (2024) and Hematian et al. (2025), pilot operation inefficiencies flow over to port labor, environment, and logistics, and pose the challenge across industries that demands scalable digitization.

Technology Solution:

Research from ScienceDirect (2024) and the Journal of Shipping and Trade (2024) highlights how integrated optimization of pilot and carrier routing improves efficiency in busy maritime corridors.

According to Milad Hematian, Audy and Rönnqvist (2025), digital port operations that incorporate real-time data significantly improve responsiveness and operational resilience.

Feature	Manual System	Proposed System
ETA Updates	Manual estimation, often inaccurate	Live updates via AIS and ML prediction
Scheduling Method	Spreadsheets, whiteboards	Drag-and-drop digital scheduling
Communication	VHF radio, phone calls	In-app or platform notifications
Conflict Alerts	Rare or delayed awareness	Instant system-generated alerts
Reassignment Time	Significantly longer, often leading to multi-minute delays	< 1 minute via dashboard tools
Stakeholder Coordination	Fragmented, often reactive	Integrated and proactive

Figure 1: Manual vs Smart System Comparison – Improvements introduced by the proposed digital system over traditional practices.

Stakeholder	Benefit
Control Center Operators	Real-time visibility, alerts, and smarter pilot schedules
Port Pilots	Reduced idle time, accurate routing updates, timely assignments
Harbor Masters	Improved safety compliance and operational oversight
Tugboat Crews	Precise coordination based on live ETAs
Ship Captains/Duty Officers	Timely and consistent updates on pilot arrival

Figure 2: Stakeholder Benefit Table – Summary of how each stakeholder group benefits from the proposed system.

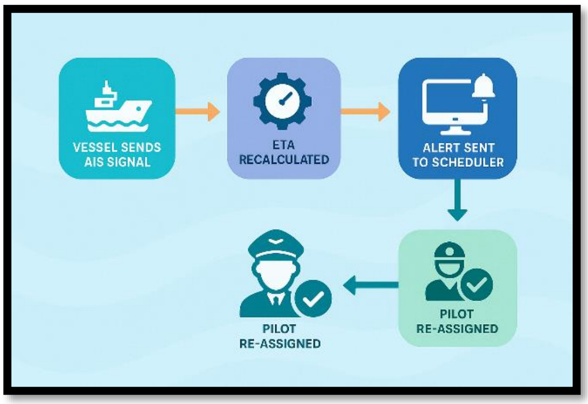

Figure 3: System Workflow Diagram – Real-time routing and scheduling using AIS data, alerts, and automated reassignment.

Personas and User Insight

The control center operators handle real-time traffic control of the port. They serve as the central coordination hub of the harbor, monitoring ship and pilot boat movements while communicating with key stakeholders including pilots, ship captains, tugboats, and harbor control.

They operate from the Vessel Traffic Services (VTS) Centre and are a critical element in executing and modifying pilot routing and scheduling.

How They Assist in Routing Pilots:

- Live Monitoring: With AIS, radar, and CCTV, track the ships, pilot, and tugboats.
- Traffic Coordination: Navigate the pilot boats to boarding points that are safest and fastest.

- Conflict Avoidance: Avoid overlapping of ships and traffic conflicts.
- Routing Changes: Divert the pilots during traffic overload, bad weather, or emergencies.
- Safety Oversight: Keep a watch for hazards and coordinate rerouting in case of dangerous situations (when fog, high wind, etc.).
- Communication Relay: Serve as an interface for decisions of port management and ongoing vessel movement.

Pain Points:

- Fragmented Systems: Currently rely only on disconnected tools like AIS, radio, and spreadsheets that are not efficient for communication.
- Manual Re-Rerouting: Adjustments are time-sensitive and require fast decision-making without automation.
- Delayed Updates: Lacks tools to anticipate disruptions caused by weather or ETA changes.
- Communication Gaps: Always busy juggling radios, phones, and emails to communicate with pilots, captains, and dispatchers.
- Stress Environment: Provides vessel safety in real-time, but without the help of intuitive digital interfaces.
- Scenario Planning: Cannot consider rerouting options or simulate changes in advance.

Possible solutions:

- One, unified dashboard of pilot, ship, and tug status
- Real-time alerting of delays, scheduling conflicts, and weather disruptions
- Rerouting tools to reroute pilot boats efficiently with live data
- Strong communication with pilots, dispatchers, and harbor masters
- Predictive tools or AI suggestions to make routing recommendations
- Performance monitoring to know what decisions worked

The proposed approach may likely counter the inconveniences raised earlier in the draft related to manual scheduling, lack of real-time coordination, and unsafe and inefficient deployment of pilots, through a responsive and conjoined digital architecture centered on Real-time Ship Tracker-meaning AIS integration-and the app interface for both control center operators and port pilots.

The system's heart includes live vessel tracking. An AIS (Automatic Identification System) fusion allows the system to ingest continuous data streams broadcast out by ships, including vessel name, MMSI number, current GPS position, course, speed, and ETA. This data must be rendered on an interactive digital map where the movements of ships are continuously updated. Let's say the ship decides to alter its course or speed on account of inclement weather, congestion, or emergency; the system recalculates the ETA and cautions the control center accordingly.

Such a tool is applied when changes are made on an unplanned basis. For instance, Luis is monitoring four incoming vessels with a VTS and MV Ocean Star slowed down due to strong winds off shore. A couple of seconds pass before the live tracker detects the slowing, recall 13:45 from the previous 13:20, and alerts Luis's screen with a red alert. The system also shows that Pilot A has been assigned to Ocean Star and that the pilot should be engaged for another ship at 13:50, creating a conflict. With the scheduler, Luis reassigns Pilot A temporarily, notifies the tugboat and ship bridge, and alters the pilot boat course, all in a few clicks.

This functionality not only solves last-minute ETA issues but also empowers operators to act proactively. The platform integrates:

- AIS-based live map: For ship tracking and ETA monitoring.
- Marine Weather API overlays: To visualize tide, fog, wind, and potential delays.
- Predictive ETA models: That improve predictions based on course and weather conditions.
- Alert System: Flags delays, schedule conflicts, and rerouting needs.
- Scheduling Interface: Allows drag-and-drop reassignment of pilots.
- Communications Module: Notifies pilots, captains, and tugboats in real time.

The app interface will be seen by both on-board pilots and control center personnel. Control center operators use it via a web dashboard—viewing the map, assignment tool, and alerts.

This system efficiently removes chronic inefficiencies in seaborne operations. Synchronizing communications and provision of real-time data, it significantly reduces cases of pilot idleness and uncertainty at ship delay. Outdated arrival forecasts and piecemeal radio communications based on them are replaced by an open platform with the transfer of lucid and timely instructions. The outcome is a notable enhancement in the capacity to make decisions and overall performance.

For control center operators—individuals often working in high-pressure conditions since they multitask continually—this technology is a revolution in workflow. Rather than having to navigate their way through a quilted quilt of spreadsheets and radio channels, these professionals can track port movements through a single aggregated dashboard, limiting the potential for human failure and mental exhaustion. The benefits resonate with stakeholder groups:

- Port pilots receive accurate assignment information that saves time.
- Situational awareness in real time and procedure automation is provided to control center operators.
- Harbor masters can manage port safety and compliance with more confidence.

- Ship captains and tugboat personnel receive integrated information, allowing for coordinated response.

This reply meets the world's port industry’s evolving needs: digital connectedness, efficiency, and sustainability. By automating and streamlining processes that previously depended on coarse estimates and human intuition, the system renders pilotage more proactive and evidence based. The ability to move towards automation also makes pilotage safer, more so by ensuring that port operation is maintained in harmony with the expectations of technology in modern times.

According to Almeida (2023), digital transformation in ports faces significant challenges including legacy systems, data silos, and change resistance.

Recent research from Swedish ports emphasizes that digital transformation in maritime operations is often hindered by organizational resistance, legacy systems, and lack of interoperability (ResearchGate, 2023; Jović et al., 2024).

Adoption Plan and Implications

To modernize pilot operations, ports must implement a centralized, AI -enabled management system integrating scheduling, tracking and forecasting tools. This includes a Dynamic Pilot Scheduler, a Real-Time Ship Tracker with AIS integration, and an AI-Driven Weather Forecasting Module. The following implementation and adoption strategy are a step-by-step approach accompanied by critical evaluation of the broader implications.

The approach is meant not just to enhance efficiency in operations but to offer secure, sustainable, and responsive port operations for more dynamic maritime environments.

1. Implementation Strategy

The centralized system must be implemented through a structured, four-phase approach that integrates pilot scheduling, real-time ship tracking, and AI-driven weather forecasting. These technologies must work in synergy to deliver timely, informed decisions for all port stakeholders.

Phase 1: Infrastructure Assessment and Planning
Port authorities should audit current infrastructure including AIS coverage, network capabilities, and existing scheduling tools. Compatibility with weather APIs and availability of environmental sensors (e.g, buoys, AWS), This includes:

- Evaluating AIS signal coverage, current scheduling tools, and network readiness.

- Assessing the availability and placement of weather sensors such as smart buoys, coastal AWS stations, and tide gauges.
- Ensuring compatibility with weather forecasting APIs (e.g., Tomorrow.io, IBM Weather) to enable hyper-local, real-time environmental alerts.
- Identifying integration points between ship tracking systems and pilot scheduling software.
- Defining technical specifications for the core platform, including cloud infrastructure (e.g., AWS or Azure) and database architecture (e.g., PostgreSQL for relational data, time-series database for sensor data)

Phase 2: Pilot Testing and System Development (Estimated Duration: 4-6 Months)
Conduct functional trials of the dynamic schedular using real-time crew and vessel data. Simulate delays (e.g., fog, wind) to assess system accuracy and response effectiveness:

- Test the Dynamic Pilot Scheduler with real-time crew, vessel, and task data to ensure accurate, efficient assignments.
- Simulate weather-induced delays (e.g., fog, wind surge) to evaluate predictive accuracy and contingency response effectiveness.
- Monitor how well the AIS module synchronizes with weather alerts to provide early warnings and ETA updates.
- Gather detailed operator feedback to refine user interface components.
- Develop the core AI algorithms for predictive ETA and optimal route calculation (e.g., using machine learning models like Random Forests or Neural Networks trained on historical traffic and weather data).
- Conduct security penetration testing and vulnerability assessments.

Phase 3: Full Scale Rollout and Training (Estimated Duration: 3- 4 Months)
Following successful testing, the system must be deployed across all active terminals. This rollout must include:

- Comprehensive, role-specific training for pilots, schedulers, and control center staff using real-case simulations.
- Integration of weather overlays and predictive alerts into operational dashboards.
- System-driven decision support tools to assist with tugboat reassignment, berth prioritization, and fatigue-based pilot management.
- A continuous feedback mechanism to adjust scheduling algorithms and dashboard visuals.
- Establish a dedicated 24/7 support team for immediate issue resolution.

- Figures 5 and 6 illustrate early stage, hand drawn interface planning sketches to support this phase.

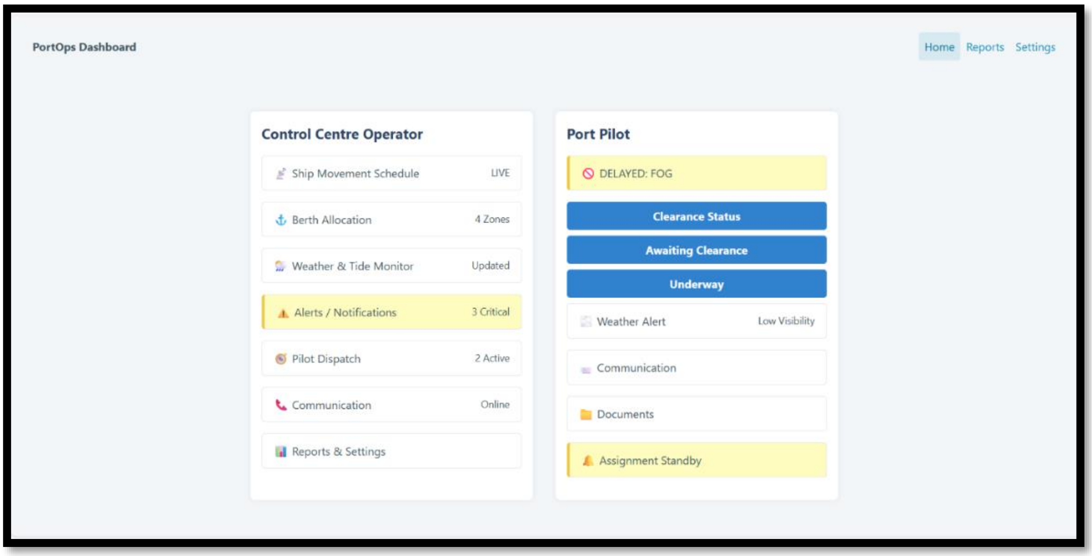

Figure 4: Visual Mockup of the Centralized Dashboard Interface

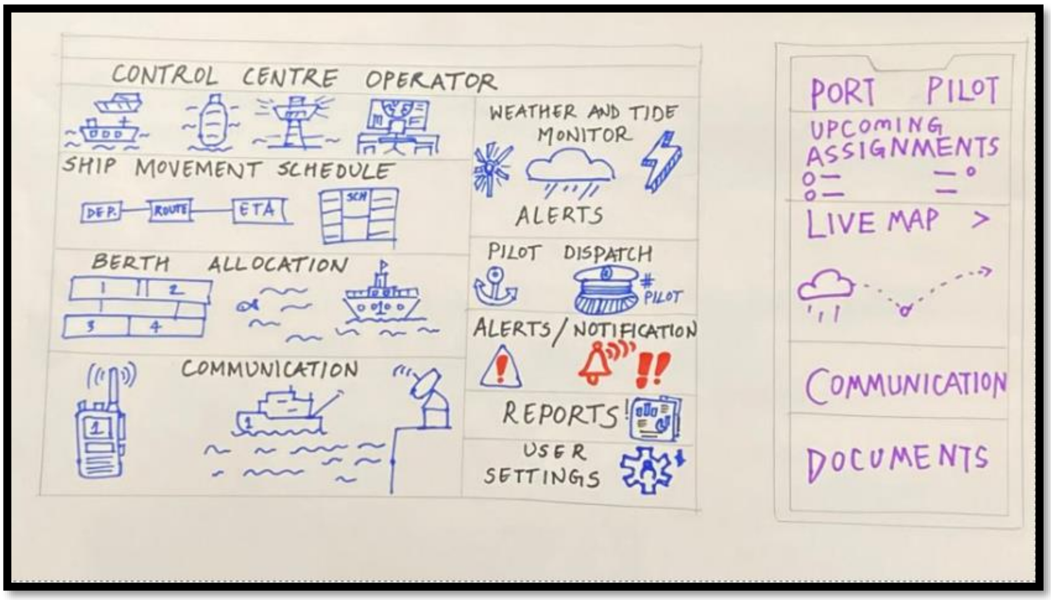

Figure 5: Initial Wireframe of Dashboard Interface

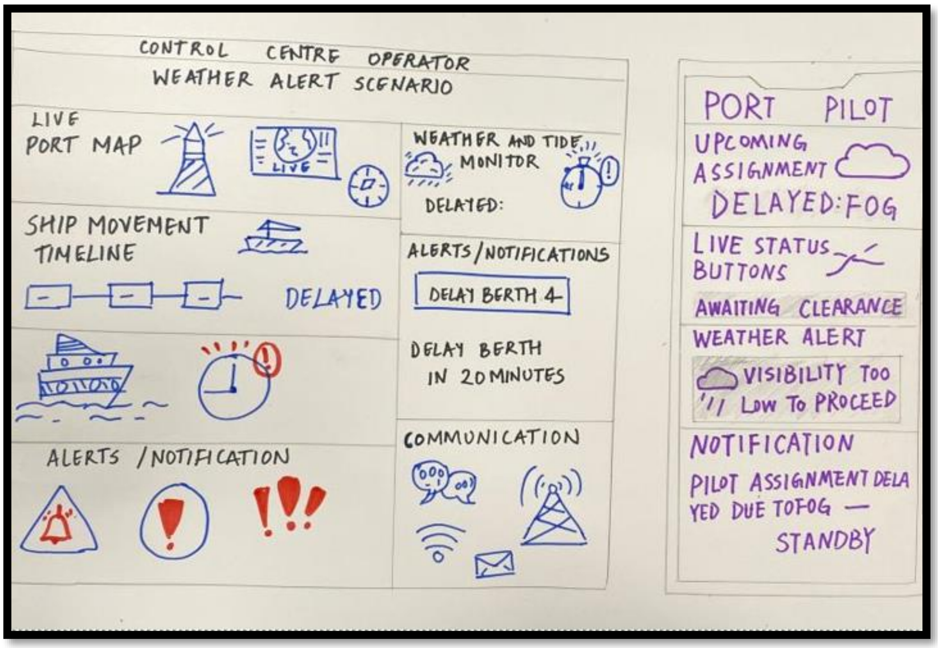

Figure 6: Weather Alert Scenario Wireframe

Phase 4: Monitoring, Support, and Continuous Improvement
Long-term success requires:

- Tracking of performance indicators such as pilot response time, delay reductions, CO2 emissions saved and forecast accuracy.
- Weekly updates to the machine learning models to reflect seasonal shifts, evolving port dynamics, and new data inputs.
- Routine updates to weather APIs, hardware calibration of weather sensors, and cloud system performance audits.
- Ongoing stakeholder workshops to review operational outcomes and share lessons learned.

Challenges and Required Actions:

- **System Integration:** Must be addressed with robust middleware (e.g., API gateways, message queues like Kafka or RabbitMQ) and layered architecture to ensure seamless communication between subsystems.
- **Operator Resistance:** Must be mitigated through participatory design, early involvement, and continuous training. Conduct workshops demonstrating tangible benefits (e.g., reduced stress, improved safety) and establish 'super-users' within each team to champion adoption.
- **Budget Constraints:** Must be addressed through grants, shared infrastructure models, and private-sector partnerships. Explore Public – Private Partnerships (PPPs) and seek grants from national and EU innovation funds (e.g., Horizon Europe) for maritime digital transformation.

Resources Required:

- **Technological:** AIS receivers, weather sensors, smart devices for pilots, cloud-based infrastructure. Requires robust broadband connectivity across the port area and secure data storage solutions.
- **Human:** Maritime AI engineers, systems trainers, control room coordinators, IT support staff. Dedicated change management specialists will also be crucial.
- **Financial:** Initial Investment of approximately €1.5 - €3 million for a medium-sized port (estimated based on typical costs for similar digital transformation projects in the maritime sector where detailed figures are not publicly available), where projected annual operational savings of 10-15% (Shipfinex.com, 2025; Sedna, 2024) and a potential ROI within 3-5 years due to reduced fuel costs, optimized resource allocation, and minimized delays.

2. Adoption Strategy

Widespread adoption of the centralized system requires a deliberate change management strategy and cross-sector collaboration.

Change Management Actions:

• Involve critical stakeholders such as control center operators, pilot associations, and port regulators from the beginning.
• Provide interactive onboarding programs specific to each user group's day-to-day working procedures, i.e., weather response training.
• Provide open avenues of user feedback,
and incorporate all findings immediately into system enhancements.
• Publish success stories and metrics from the pilot phase to demonstrate real-world value. Showcase tangible improvements like a 14% reduction in pilot waiting times (Hematian, Audy, and Rönnqvist, 2025) or significant CO_2 savings, such as 6,000 tons annually for a large port (IMO, 2025).

Strategic Partnerships Must Be Established With:

- Maritime AI and analytics companies to continuously refine algorithms.
- Weather and oceanography experts monitor accuracy and adapt to climatic trends.
- Academic partners to evaluate system impacts and co-develop responsible AI protocols.
- Environmental agencies to align port emissions reductions with global targets (e.g., IMO 2030).
- Key maritime technology providers and software developers to ensure seamless integration and future scalability.

To Sustain the Solution Long-Term, Ports Must:

- Formalize a support structure including a helpdesk, troubleshooting team, and update task force.
- Establish KPIs to measure system effectiveness over time, with annual performance reviews. Key performance indicators will include pilot utilization rates, average vessel turnaround time, fuel consumption per pilot trip, and deviation from optimal routes.
- Ensure modularity for easy expansion to additional terminals or regional port clusters.
- Plan for future-proofing the system through interoperability standards and scalable data storage.

3. Ethical, Legal, Societal, and Environmental (ELSE) Implications

Ethical & Legal Responsibilities:

- **Data Protection:** All sensitive data, including GPS locations, potentially sensitive operational data, and pilot biometric indicators, must be stored and transmitted using end-to-end encryption. Adherence to GDPR and other relevant data privacy regulations is paramount.
- **Transparency in Automation:** All AI recommendations—especially in high-stakes decisions like rerouting due to weather—must be documented and explainable.
- **Accountability:** Establish clear lines of responsibility for system failures or erroneous AI recommendations.

Societal Responsibilities:

- **Workforce Adaptation:** Job transitions must be supported through retraining programs and reallocation of staff to data oversight and system management roles.
- **Equitable Access:** Small or resource-constrained ports must be supported through tiered pricing, open-source alternatives, or government incentives.
- **Community Engagement:** Communicate the benefits of improved port efficiency (e.g., reduced air pollution from ships) to local communities.

Environmental Impact:

- Positive impacts include reduced fuel usage and emissions via optimized routing and minimized idle time. This could lead to an estimated 5-10% reduction in fuel consumption per pilotage operation (Sinay, 2025; Innovez One, 2024).
- Weather-responsive planning avoids wasteful operations during unsafe conditions and contributes to IMO decarbonization targets.
- Energy use and e-waste from digital infrastructure must be managed through eco-efficient hardware and recycling policies.

4. Future Outlook

The centralized platform must become the core of a future-ready Smart Port ecosystem. Key future advancements must include:

- Integration with autonomous vessel scheduling and AI-supported berthing logic.
- Inclusion of digital twin technology to simulate storm, congestion, and emergency scenarios.
- Expansion of machine learning to include weather anomaly forecasting and long-range climate risk modeling.
- Blockchain-based logging for transparent and tamper-proof pilot and tug assignments.
- Integration with smart city initiatives to optimize last-mile logistics for cargo.
- Development of predictive maintenance schedules for pilot boats based on operational data.

Adopting this centralized system is a strategic imperative—not just for efficiency but for safety, sustainability, and long-term competitiveness in a rapidly evolving global maritime industry.

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