AI PORT CENTER

Responsible AI in the Cargo-Handling Sector

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Jose Gallegos Quezada
Erasmus UPT

TU Delft

Erasmus University Rotterdam

Contents

Disclaimer

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1. Introduction

Artificial Intelligence (AI) is transforming the cargo-handling sector, impacting operational efficiency, workforce dynamics, and regulatory frameworks. AI adoption is increasing across industries, with logistics and maritime operations becoming increasingly AI-driven. AI provides immense potential for improving quality, speed, and
operational efficiency in cargo handling by eliminating repetitive tasks, optimizing scheduling, and enhancing safety.

Object of the Study

This research aims to identify future areas of study at the intersection of:

- AI and Ethics: Addressing the ethical challenges of AI-driven automation, including fairness, transparency, and accountability in workforce management.
- Employment Relations: Examining how AI affects job roles, employment security, and collective bargaining strategies.
- Technology Implementation: Assessing the feasibility and impact of AI applications in operational processes, safety measures, and decision-making.

Scope of the Project

This study is structured around two key aspects:

(1) Technology Catalogue: Mapping AI applications currently in use or under development within cargo handling and logistics.

(2) Labor Assessment: Evaluating how AI is transforming job roles, decision-making processes, and labor-management relations at port terminals.

A Technology Catalogue is essential for organizations aiming to fully leverage the opportunities of AI. To do so, they must possess sufficient in-house knowledge to stay up to date with current developments and integrate them effectively into their operations. The developed catalogue helps lower this threshold by providing managers and other stakeholders with an accessible overview of available AI products and their functionalities. This not only enhances understanding of technological possibilities but also offers valuable insights into the potential impact of these technologies on existing work processes and organizational structures—particularly from a Human Resource Management (HRM) perspective. In conclusion, the catalogue facilitates the broader dissemination of AI knowledge across all levels of the organization. It enables companies to identify opportunities, assess potential risks, and make informed decisions regarding the responsible adoption of AI in the workplace.

Furthermore, AI significantly influences the nature of work, although the scale and direction of this impact remain uncertain. To better understand and scope this impact, we have developed a Labor Assessment that examines both the scale and direction of AI's effects on work. Globally, AI is

expected to influence not only the number of Full-Time Equivalents (FTEs) required but also the type of work people perform[1][2].

2. Methodology

2.1. Overview

To ensure a comprehensive understanding of AI's impact on cargo handling, data was collected from multiple sources:

Interviews: Conducted with port authorities, terminal operators, union representatives, and technology providers.

ID	Stakeholder Type	Organization
241127	Port Authority	Port of Rotterdam Authority
241219	Port Authority	Portbase
241203	Scholar	TU Delft
241220	Scholar	TU Delft
241212	Tech Vendor	Seagull (OCR-Company)
250130	Tech Vendor	Kalmar
250206	Tech Vendor	Kaleris + Navis
241128	Terminal Operator	Rotterdam Shortsea Terminals (RST)
241212	Terminal Operator	Hutchinson ECT
240927	Terminal Operator	Rotterdam World Gateway (RWG)
241108	Union	UGT (Spain)
250206	Tech Vendor	eeSea

Table 1: *Overview of interview sources*

Literature Review: Synthesizing academic research, policy reports, and industry publications.
Media Analysis: Reviewing newspaper articles and trade publications on AI implementation in ports.
Legal Documents: Examining collective bargaining agreements (CBAs), labor regulations, and relevant AI legislation.
Field Research: On-site observations at:
Pier 400 – APM (Long Beach, Los Angeles)
TraPac (Long Beach, Los Angeles)
Port Technologies Congress (Rotterdam)

2.2 Data Analysis

2.2.1. Conceptualization of AI

A fundamental challenge in this research was determining the best approach to conceptualizing AI in the cargo-handling sector. Two possible methodologies were considered. One option was to establish a predefined conceptualization of AI grounded in academic and technical literature and then identify products and applications that aligned with this theoretical framework. The alternative was to rely on how AI is self-identified by industry players, analyzing the claims of technology providers, port operators, and logistics firms as they present their own AI-driven solutions.

1 ChatGPT is about to revolutionize the economy. We need to decide what that looks like. I MIT Technology Review

2 Artificial Intelligence and the Labour Market I OECD Employment Outlook 2023

Both approaches offer distinct advantages and challenges. Constructing a predefined conceptualization of AI before identifying products ensures theoretical clarity and prevents the risk of AI being misrepresented or exaggerated by companies for marketing purposes. It allows for a rigorous distinction between AI and conventional automation, filtering out technologies that rely solely on pre-programmed rules rather than machine learning or adaptive decision-making. However, applying a rigid definition of AI risks overlooking how the industry itself understands and deploys artificial intelligence. Many AI applications in the cargo-handling sector exist within a continuum of digitalization, where traditional automation, predictive algorithms, and data-driven decision support systems overlap. Defining AI narrowly based on scholarly or regulatory standards could result in excluding relevant technological innovations that port operators and logistics firms consider part of the AI ecosystem.

The alternative approach, which this study adopts, focuses on how AI is self-identified within the industry. This method provides insight into how AI is marketed, perceived, and integrated into real-world operations, offering a more accurate reflection of the sector's evolving technological landscape. Although relying on industry self-identification carries the risk of inflated AI claims, it allows for an empirical examination of how companies define and deploy AI. This approach also facilitates engagement with stakeholders, as port authorities, logistics providers, and terminal operators often operate based on their own interpretations of AI

2.2.2 Product Identification

The second stage of analysis focused on systematically identifying self-claimed AI technologies in cargo-handling operations through a multi-source approach. Industry exhibitions, such as the Port Technologies Congress in Rotterdam, provided direct engagement with vendors, allowing us to collect brochures, photos, and presentations and examine product capabilities firsthand. For events we couldn't attend in person, we analyzed their programs, identified key vendors, and subsequently visited their websites to gather additional information. Industry white papers and implementation reports supplemented this analysis, offering insights into use cases and technical specifications. Interviews with terminal operators, consultants, and vendors further expanded our catalogue, often revealing additional AI products and clarifying distinctions between products and vendors.

Congress	Location
Smart Digital Ports of the future	Rotterdam
Container Terminal Automation Conference Europe	Valencia
Intermodal Container Terminal Conference TPM25	Düsseldorf
Port Technology Summit North America	Long Beach, Virginia
Greentech for Ports and Terminals	Gothenburg

Table 2: Congress Product Identification

As our identification process progressed, we reached a key realization: AI technologies and AI applications needed to be treated as distinct categories. Technologies—such as machine learning, deep learning and fuzzy logic—constituted the building blocks of AI solutions. We also recognized, however, that other technologies not directly classified as AI (such as 5G networks, digital twins, and cloud computing) frequently enabled these AI technologies. Therefore, we incorporated all these technologies under the broader umbrella of "Enabling Technologies" (see Table 2). Applications, in contrast, referred to the specific implementation of these technologies in port operations, including vessel scheduling, risk assessment, and automated surveillance systems (see Table 2). Recognizing these distinctions proved essential for the labour assessment phase of our

report, where we analyzed how specific applications—rather than underlying technologies—impacted different dimensions of labour in the cargo-handling sector.

What Constitutes an AI Technology vs. and AI Application?

AI Technologies: Fundamental methods and models that enable AI to function (e.g., Machine Learning, Computer Vision, Deep Learning).
AI Applications: The practical use of AI technologies to solve specific industry problems (e.g., predictive maintenance, berth scheduling, automated surveillance).

AI Core Technologies	AI Peripheral Technologies
Machine Learning	OCR
Deep Learning	Blockchain
Natural Language Processing (NLP)	Cloud computing
Bayesian Networks	Internet of Things
Fuzzy Logic	5G Network
	Digital twins

Table 3: Overview of AI Technologies

Terminal Optimization	Personnel Management
Dynamic routing	Task allocation
Dynamic scheduling	Performance assessment
Predictive maintenance	Recruitment
Predictive analytics (Operation simulations)	Safety compliance
Automated incident response	Shift scheduling
Data integration	
Object identification	

Table 4: *AI applications*

For example, when analyzing YardSight (Figure 1), we identified "AI-Powered Digital Twin Modelling" as the enabling technology and "Predictive Analytics" as the AI application. The product description explicitly states that YardSight "creates a virtual replica of your yard by using AI-powered digital twin modelling" (enabling technology) which then supports "predictive container movement analysis" where it "employs predictive algorithms to analyze historical and real-time data" (AI application). These capabilities are ultimately directed toward "Terminal Optimization," where the technology potentially affects operational workflows and job functions, providing crucial context for our labor assessment. By categorizing YardSight in this structured manner, we could more precisely evaluate how its specific implementations might impact terminal workers beyond simply noting the presence of advanced technology.

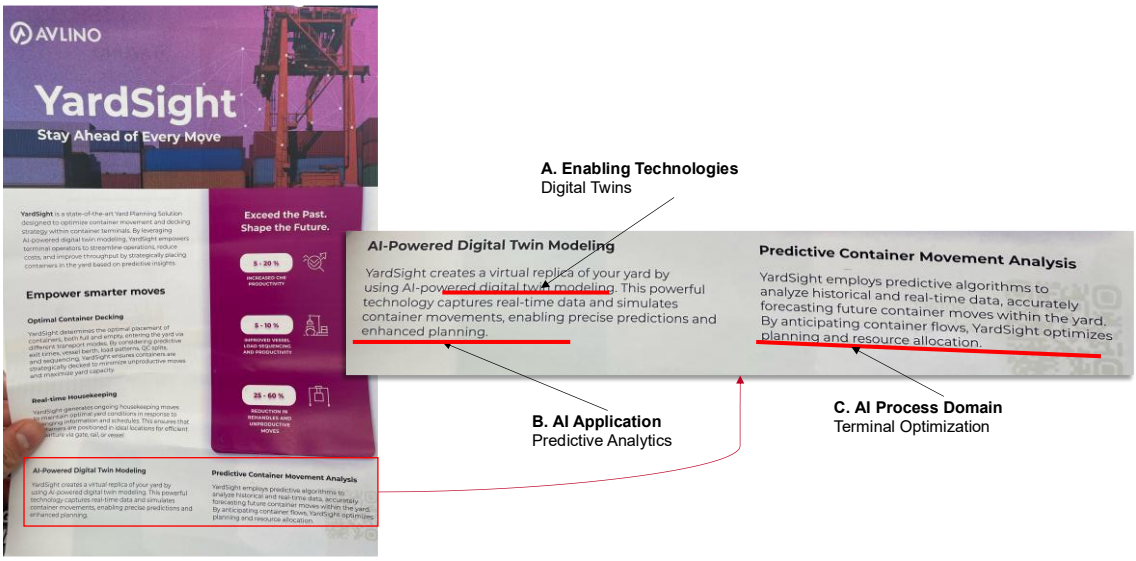

Figure 1: *Leaflet of YardSight*

2.2.3 Usage Domain Framework

To systematically assess the role of artificial intelligence (AI) in cargo-handling operations, we developed a multi-level framework that categorizes AI implementation across distinct operational domains, as shown in Table 3.

Level	Scope	Labor Impact
1. Personal Productivity	Cross-industry	Low
2. Personnel Management	Cross-industry	High
3. Terminal Optimization	Sector-specific	High
4. Port Optimization	Sector-specific	Medium

Table 5: *Level of AI applications*

Each level represents a different degree of AI integration and its implications for labor. *Personal Productivity* refers to AI tools designed to enhance individual workflows, such as meeting summarization and email drafting. *Personnel Management* consists of AI-driven systems that oversee human resources at the company level, including staff scheduling, task allocation, and performance assessment. *Terminal Optimization* captures AI solutions that enhance core business processes within terminal operations, including predictive maintenance and customer service automation. *Port Optimization* refers to cross-organizational AI platforms that facilitate collaboration between multiple stakeholders through integrated data flows, such as vessel ETA prediction and multi-party supply chain optimization.

Research Focus and Methodological Rationale

This study strategically focuses on Levels 2 and 3, *Personnel Management* and *Terminal Optimization*, due to their immediate impact on labor and their current stage of implementation. The preliminary labor impact assessment highlights that AI adoption in these domains poses significant risks to workforce stability, particularly through the automation of task allocation, scheduling, and operational decision-making. These roles have emerged as the most vulnerable to AI-driven transformations. While Level 1 applications are already widely integrated with minimal labor implications and Level 4 applications remain in early development, Levels 2 and 3 are actively being deployed and tested in operational environments, providing opportunities for direct observation and empirical analysis.

By concentrating on these middle levels, the research enables a targeted examination of the socio-technical transition occurring as workers adapt to AI-assisted operational roles. This shift,

particularly toward "process controller" positions, represents a fundamental transformation in maritime terminal labor dynamics and serves as a critical focal point for understanding AI's broader implications in the sector.

2.2.4 Development of Labor Dimensions

The Labor Assessment Framework was developed through a literature review on technology adoption in industrial settings and refined using thematic analysis of stakeholder interviews. This process identified four primary dimensions, each with corresponding variables, to comprehensively assess AI's impact on port workers.

Dimention	Variables
D1. Employment	Job Displacement
	Workforce Composition
D2.Safety	Occupational Safety
	Terminal security
	Privacy
D3. Job Experience	Task Complexity
	Autonomy & Surveillance
D4. Fairness of Treatment	Career Advancement
	Performance Assessment
	Task Allocation

Table 6: *Labor dimensions impact of AI applications*

The framework is structured to progress from macro-level workforce effects (D1) to organizational concerns (D2), and finally to individual worker experiences (D3 and D4). This approach ensures a nuanced analysis that moves beyond simplistic job replacement narratives, capturing both quantitative workforce shifts and qualitative transformations in job roles, autonomy, and oversight. By distinguishing these different levels, the framework allows for a more detailed examination of how AI-driven changes impact labor dynamics at multiple scales, from broad employment patterns to specific workplace practices.

Each variable was selected based on its recurrence in both academic literature and stakeholder concerns. For instance, the inclusion of "Privacy" under Safety emerged from union representatives highlighting AI-driven surveillance in the workplace. Similarly, "Task Complexity" addresses how AI restructures cognitive tasks by automating routine decision-making processes, shifting workers into more monitoring and process-control roles[3]. AI can "displace human tasks", leading to job loss or significant changes in job content. At the same time, it can assist workers in performing tasks, thereby enhancing their capabilities and promoting greater inclusion in the labor market. AI can also create new tasks for people, requiring new skill sets and reshaping the "composition of the workforce". However, these developments are not without risks. One concern is "excessive monitoring of workers", which may reduce "autonomy" and increase stress. Moreover, the automation of meaningful tasks can erode job satisfaction, especially when it diminishes the sense of purpose or engagement in one's work. The implementation of AI may also lead to stress, psychosocial workload (PSA), and unsafe working conditions[4], particularly when technologies are introduced without adequate safeguards or support mechanisms.

This framework served as a foundation for data collection and interview coding, ensuring a systematic and comprehensive evaluation of AI's multifaceted implications for cargo-handling

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workers. By structuring the analysis across multiple dimensions, it facilitates a holistic understanding of AI's role in reshaping labor conditions, ensuring that both challenges and opportunities are thoroughly examined.

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3 Key Findings/AI Applications

3.1 Energy Efficiency Application

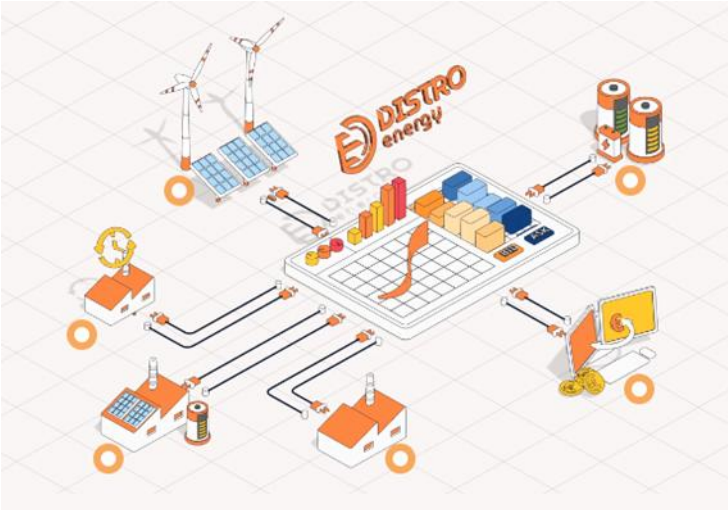

Figure 2: *Distro Energy's marketplace*

An example of an AI applications which improve the energy efficiency is Distro Energy's marketplace created by S&P Global Platts dynamically connects renewable energy producers with power consumers. AI agents place bids and asks on the marketplace that are based on your power forecast. Automated trading with an AI agent, the agent expertly navigates the market. Utilizing frequency trading algorithms, while continuously adapting to fulfil companies energy requirements within defined time frames.

3.2 Comprehensive Traceability Application

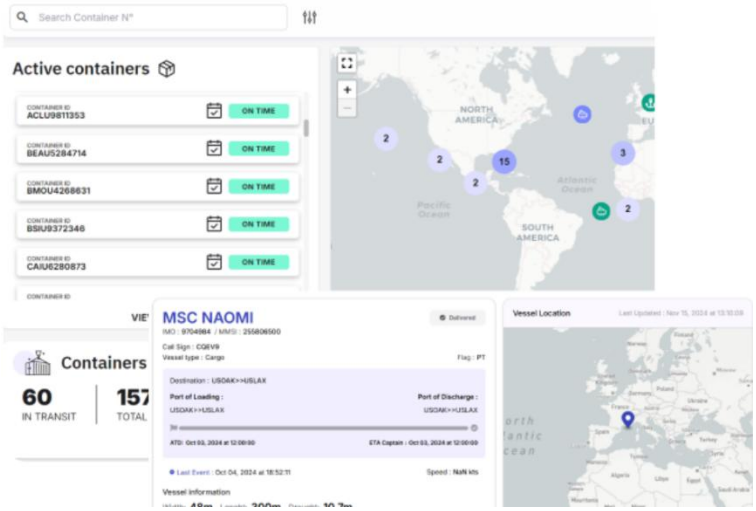

Figure 3: *Safecube of SINAY*

An example of an AI applications which improve comprehensive traceability is Safecube of SINAY, with this application users can enter the booking, container or bill of lading , and will be provided with complete container journey, including milestones, current location, vessel schedule, and transshipment info, all in one platform.

3.3 Decision Making Application

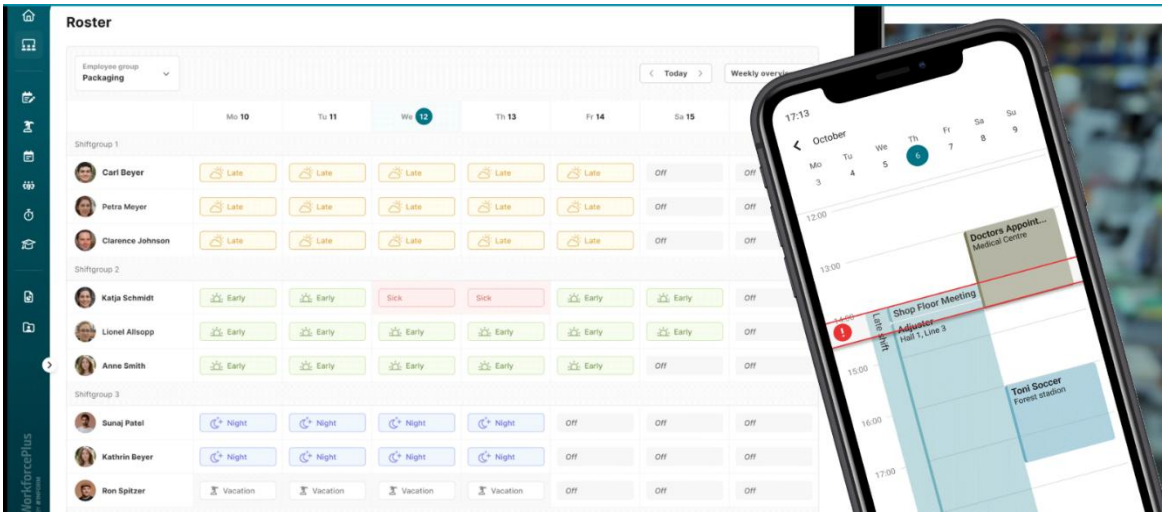

Figure 4: *Workforce Management of INFORM*

An example of an AI applications which improve the decision making process is Workforce Management of INFORM combines staffing requirements, the needs of employees and statutory and regulatory requirements, Collective Labor Agreements and employment contracts. It is optimized, demand-oriented employee scheduling finds the best possible balance for the specific goals and conditions. This improves employee engagement, working time productivity and customer satisfaction by creating schedules that match requirements (rules and qualifications), Involve employees, integrates seamlessly into existing system landscape and adapts flexibly to individual requirements.

4. Key Findings/Labor Impact

4.1 AI Automation Targets Cognitive Tasks Over Physical Tasks

Our research reveals a counterintuitive pattern in AI-driven automation within port terminals: cognitive tasks are more vulnerable to automation than physical tasks. Unlike earlier waves of automation that primarily replaced manual labor, AI systems are predominantly affecting roles with higher cognitive components.

Finding 1a: *The greater the degree of context-specific decision-making in a role, the harder it becomes to codify tasks, making worker substitution by AI systems more challenging.*
Finding 1b: *Unlike robotization, AI automation predominantly affects roles with a higher degree of cognitive tasks rather than those involving primarily physical tasks.*

Case Study: Crane Operators vs. Vessel Planners

Our comparative analysis of different terminal roles illustrates this pattern clearly. Crane operators, despite performing a physical task, remain difficult to automate due to three key factors:

Situational awareness challenges: As one terminal operator explained, "If you can get a real-time overview of the situation, the situational awareness so to speak, then you can also automate the equipment itself. But that's not something we can buy now, and I think it will be developed in five or six years maybe."
Environmental variability: High variance in conditions like wind, tides, and structural obstacles creates complex decision scenarios that resist algorithmic codification.
Business case limitations: The technological sophistication required for full automation presents questionable ROI given current capabilities.

Industry experts confirm this challenge: "You would be amazed at the number of decisions a crane operator makes on a simple lift—trying to program all of that is a very big technical challenge" (Casper, Phillips & Associates - Globally Recognized Crane Engineering Services). But in the end, they all strive for full automation as suggested by Paul Ham, of ECT: "So we use artificial intelligence and machine learning to assist the crane driver as much as possible. And in the end, we hope to skip the crane driver and that the whole process can be done automatically."
In contrast, clerical roles such as vessel planners are experiencing significant disruption. Our data from one terminal indicates:

Role	Current Workforce	Workforce after AI Implementation	Reduction
Vessel Planners	Total: 27 (5 gangs of 5 + 2 rotating positions)	Total: 11 (5 gangs of 2 + 1/2 rotating positions)	16 jobs (60%) Labor costs reduction: €1.5M (considering 100K annually)

Table 7: *Labor dimensions impact of AI applications*

The dramatic efficiency gains are evident in processing time:

"The normal planning process by a person takes, depending on the type of vessel, around 5-6 hours. This tool [Loadmaster AI] does it in, I don't know, 3-4 minutes."

As terminal operators described the transition:
"Their function and role will change significantly, as they will no longer handle vessel planning or the load and discharge of containers. These tasks will be managed by an AI solution. Instead, their responsibilities will shift to maintaining communication with the vessel and its captain […] The remaining staff will transition into a new role as process controllers."

4.2 Workers Unknowingly Contribute to AI Model Training

Finding 2: Workers unknowingly contribute to AI model training by providing insights into their tacit knowledge.

Our research identified three primary mechanisms through which workers contribute to AI training:
Digitalizing documents: Converting analog knowledge into digital formats that can be processed by machine learning systems
Providing feedback to AI models: Correcting errors made by AI systems
Making their reasoning process explicit: Articulating decision factors that were previously implicit

Following Sabine Pfeiffer's (2016) definition, tacit knowledge represents "a form of informal and implicit knowledge rooted in personal experience, which is often difficult to articulate, formalize, or transfer. It encompasses non-codifiable capabilities, such as sensory perception, intuition, and associative thinking, and is deeply tied to the individual's context and engagement with specific tasks or environments."

SEAGULL: Worker-AI Interaction in Port Operations

SEAGULL is an AI-driven solution designed to enhance maritime situational awareness and security operations by leveraging human feedback to refine its decision-making capabilities. Unlike conventional AI systems that operate in isolation, SEAGULL continuously learns from worker interactions, integrating real-time expertise to improve classification accuracy and risk detection.
How Workers Contribute to SEAGULL's AI Learning
SEAGULL relies on port workers—particularly harbor masters, customs officials, and security personnel—to validate and refine AI-generated insights. This interaction occurs in two key ways:

Manual Feedback for Model Correction

SEAGULL classifies maritime objects based on visual and sensor data, but workers often detect classification errors. For example, if SEAGULL misidentifies a "Rigid Inflatable Boat" as a "sailboat," workers override the AI's decision, providing direct feedback that improves future recognition accuracy. Each correction enhances SEAGULL's ability to differentiate between similar objects in subsequent operations.

Tacit Knowledge Transfer Through Explicit Reasoning

Experts in port security contribute to SEAGULL's learning by articulating the reasoning behind risk assessments. A harbor master, for instance, might explain that a vessel with unusual coloring, jerrycans on board, and no visible sails suggests potential

illicit activity. This explanation is digitally captured and integratedinto SEAGULL's AI model through a process known as fingerprinting, allowing the system to recognize similar suspicious patterns autonomously in the future.

While SEAGULL improves efficiency and security through AI-human collaboration, its reliance on worker-provided intelligence raises concerns about recognition, compensation, and labor rights. Much like digital workers in other sectors, port employees are contributing valuable expertise without necessarily receiving direct benefits from the system's enhanced capabilities.

4.3. Regulatory Barriers to AI Adoption

Finding 3: Regulatory frameworks create disincentives for developing and implementing certain AI applications, as employers seek to avoid potential sanctions and compliance risks.
Our research identified three primary regulatory frameworks affecting AI implementation in port terminals:
GDPR: Restricts the types of data that can be collected and processed
Platform Work Directive: Establishes conditions for algorithmic management of workers
AI Act: Requires AI explainability and human oversight
The AI Act is particularly significant for employment contexts. Article 86 grants individuals the right to obtain "clear and meaningful explanations of the role of the AI system in the decision-making procedure and the main elements of the decision taken" when subject to decisions based on outputs from high-risk AI systems that adversely affect their health, safety, or fundamental rights. These regulatory frameworks significantly impact the development trajectory of AI solutions in the sector, with important implications for management-union relations. Key research questions emerge regarding the transposition of the EU AI Act and the appropriate level of explainability required in different operational contexts.

4.4AI-Induced Dependencies and Vulnerabilities

Finding 4: AI integration may increase reliance on external parties, introducing vulnerabilities that compromise occupational safety and security in terminal operations.

Our analysis reveals emerging concerns regarding operational resilience when critical decision-making is outsourced to external technology providers. This is especially evident in safety-critical roles that are evolving into "Operation Controller" positions, where workers must:
Respond to unexpected events or disruptions (equipment breakdowns, accidents, weather conditions)

Adjust operational plans in real-time to ensure continuity and minimize downtime
Recent regulatory developments reflect these concerns. In the US, Executive Order 14116 (February 21, 2024) titled "Amending Regulations Relating to the Safeguarding of Vessels, Harbors, Ports, and Waterfront Facilities of the United States" grants the U.S. Coast Guard enhanced authority to respond to cybersecurity incidents, mandates reporting of cyber threats affecting maritime facilities, and proposes new cybersecurity regulations for the maritime sector.

This finding raises critical questions for future research:

To what extent could AI applications lead to dilution of accountability for hazardous operational outcomes?

How might AI implementation increase vulnerability to external attacks or unauthorized decisions from third parties?

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