THE FUTURE OF CONTROL ROOMS: DIGITAL TWIN AND AI

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Control rooms in container terminals have traditionally served as the nerve centre for planning, execution, and logistics coordination. As automation transforms terminal operations, the role of control room staff is also evolving. With technology calling time on manual oversight, personnel are now able to operate at a more strategic level. While automation has enhanced process, discipline, and reliability, real-world operations remain dynamic, unpredictable, and heavily dependent on human expertise. Current support systems often struggle with operational variability and still rely heavily on human intervention.

Digital Twin technology, combined with Artificial Intelligence (AI), now provides a path towards increased efficiency and improved resilience by:

- Enhancing operational visibility through real-time process modelling by fusing different systems' data, reducing cognitive overload for operators.
- Prescriptive decision-making and intelligent exception handling, allowing terminals to anticipate bottlenecks and disruptions.
- Assisting users with a real-time integrated continuous improvement function, rather than just providing data, while improving system intelligence over time.

This article explores how Digital Twin technology and the integration of AI are redefining control rooms, transforming them from traditional monitoring centres to intelligent hubs of operational orchestration and optimisation, enhancing the way operators interact with systems, and unlocking new opportunities for continuous improvement.

1. ADDRESSING THE CONTROL ROOM EVOLUTION GAP

One of the most underestimated challenges in terminal modernisation is organisational evolution—particularly in control rooms, where automation alone does not provide a clear roadmap for how operators should adapt, or how processes and roles should evolve.

Historically, control rooms have been staffed by experienced operators who rely on intuition, past experience, and real-time judgment to make decisions. However, as terminal automation increases the complexity of handling multi-system interactions, exceptions and real-time variability have outpaced human cognitive capacity. This challenge is not limited to automated terminals—manual terminals undergoing technology modernisation projects also experience increased complexity and scattered data across multiple systems.

The key is to bridge automation and human expertise by using AI to enhance, rather than replace, decision-making. In this transition, data intelligence and user-centric applications must complement human expertise, not replace it. The goal is not to eliminate the role of control room operators but to augment their decision-making with AI-driven insights.

2. STANDARDISATION AND INTEROPERABILITY: A DIGITAL BACKBONE FOR NEXT-GEN DECISION MAKING

Data and systems fragmentation have long been a barrier to terminal automation. The Terminal Industry Committee 4.0 (TIC 4.0) has taken critical steps toward addressing this by:

- Standardising operational data semantics (e.g. job instructions, equipment status).
- Creating interoperable frameworks for system-to-system communication.
- Enabling structured data models as the foundation for automation, AI, and predictive analytics.

Despite these advances, key challenges remain:

- Terminal systems are still highly customised and often integrated on a project-by-project basis, limiting repeatability and scalability.
- Interfaces between systems are project-specific, making it difficult to scale and replicate across terminals—particularly for Terminal Operating Systems (TOS) and Equipment Control Systems (ECS).
- Interoperability is not granted from the beginning, requiring terminal operators to manually consolidate data across systems.

By adopting standardised data models and integrating Digital Twin in operations, terminals can:

- Unify operational data, creating a digital replica of terminal logistics processes where users interact with a single intelligent interface instead of juggling multiple disconnected systems.
- Enable seamless system interoperability, allowing different platforms to work together efficiently via multi-system orchestration and applied data insights.
- Streamline exception handling, leveraging Digital Twin and AI to process cross-system data patterns, enabling intelligent alarms and proactive recommendations.

The true power of terminal automation, combined with effective AI, will only be fully realised when data flows seamlessly, allowing operational intelligence to be scalable, repeatable, and continuously optimised.

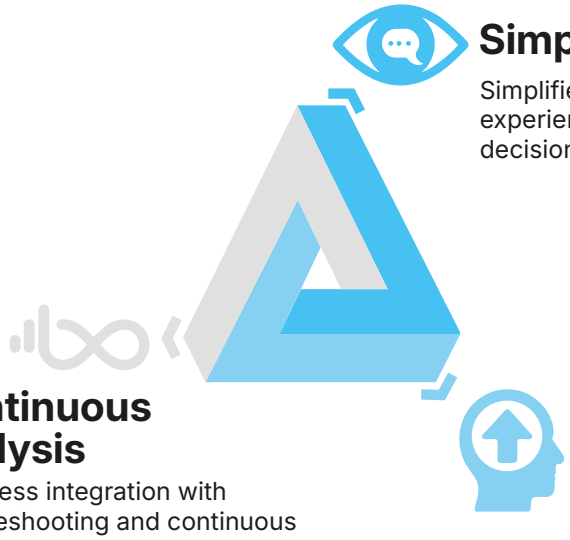
3. SIMPLIFYING USER EXPERIENCE: DIGITAL TWIN AND AI-DRIVEN EXCEPTION HANDLING

One of the biggest pain points in control rooms today is the fragmentation of user interfaces and the resulting complexity. Operators must navigate multiple independent systems, including:

- TOS job control and sequencing, also connecting planning apps and execution apps.
- ECS for real-time execution monitoring and exceptions handling.
- IoT and sensor platforms for positioning, identification, job acknowledgement, etc.
- Additional interaction with Gate Systems, connection with CHE on-board computers (VMT), etc.

This complexity leads to cognitive overload, delayed responses, and increased operational risk. A Digital Twin-powered control room simplifies this by:

Simplifying user experience with a unified view and actionable information	Manage exceptions with system guidance and behaviour analysis
A Digital Twin-based interface that consolidates real-time and historical data into a single, visual environment.	Instead of manual threshold-based alerts, the Digital Twin integrates AI to learn from operational patterns and dynamically adjusts alarm settings.
Users can interact with live terminal operations, receive analysis to anticipate disruptions, and diagnose issues more quickly.	Operators receive context-aware recommendations to make faster, more informed decisions.



Simplification

Simplified and visual user experience augments human decision-making.

Continuous analysis

Seamless integration with troubleshooting and continuous improvements.

Augmentation

Enriched data foundation for decision-making — more complete and precise context and visual experience.

FIG 1.
Simplifying UX diagram

By integrating these capabilities into a seamless control room interface, the Digital Twin allows operators to focus on decision-making instead of managing complex systems. Furthermore, the integration of AI will significantly transform control room operations in the following ways:

1. **Analysis:** Detects anomalies in real time, flagging early warning signals.
2. **Diagnosis:** Diagnoses the root cause based on historical trends and operational context.
3. **Recommendation:** Recommends optimised responses, dynamically adjusting workflows.
4. **Learning:** Learns from operator decisions, continuously improving future recommendations.

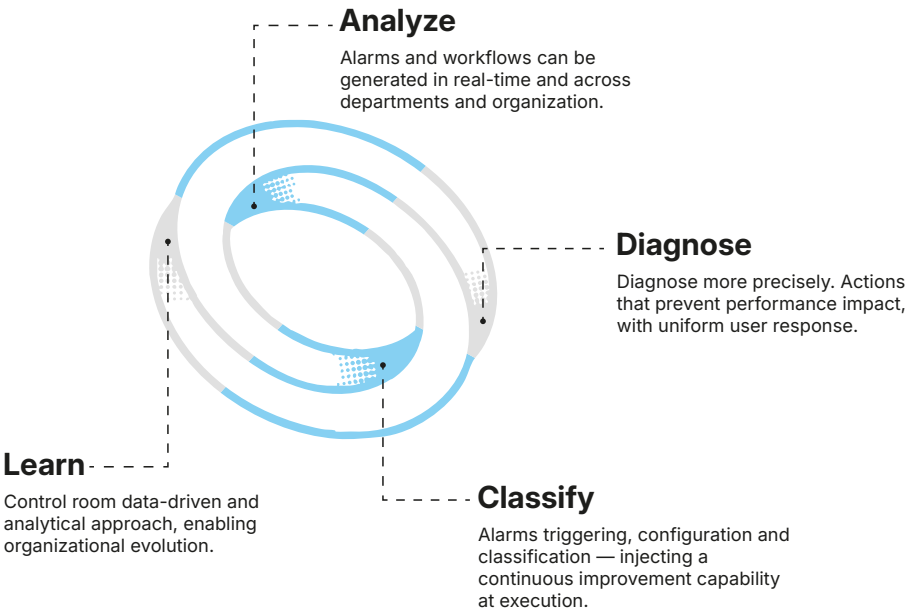
4. SYSTEMATISING CONTINUOUS IMPROVEMENT

Traditional LEAN methodologies have long been utilised in terminal operations to streamline processes, eliminate inefficiencies, and drive continuous improvement. However, these methods have historically relied on human analysis, manual data collection, and periodic process reviews.

To achieve effective continuous improvement, it is essential to connect processes, assets, and systems. This involves focusing on the root causes of exceptions and proposing corrective actions based on historical data and predictive models.

Integrating AI into the continuous improvement process enhances this approach by enabling:

- Automated process optimisation and exception handling based on real-time operational data, refining response strategies over time.
- Dynamic asset performance optimisation, reducing downtime and maximising utilisation.
- Prescriptive dynamic planning, where AI suggests proactive strategies rather than simply identifying past inefficiencies, allowing terminals to dynamically adjust planning strategies.



AI-powered continuous improvement is not just about efficiency gains—it creates self-optimising terminals where operational intelligence evolves in real time. By generating repeatable, data-driven insights across multiple terminals, operators can drive uniform improvements to serve their customers in better and different ways and modernise their business.

CONCLUSION: A NEW ERA OF CONTROL ROOM INTELLIGENCE

The future of container terminal control rooms is not just about automating existing processes but about fundamentally redefining how operators interact with technology. While technology—and automation in particular—enforces process discipline and generates vast amounts of operational data, it does not inherently understand variability or optimise decisions beyond its predefined logic. This is where evolution is required to effectively:

- Dynamically analyse operational variability instead of relying on pre-defined rules.
- Adjust planning and execution in real time, minimising inefficiencies.
- Automate exception handling, reducing workload and response time.

Digital Twin technology, combined with AI, is reshaping operational intelligence, enabling:

- A more intuitive and seamless user experience, reducing complexity and workload.
- Scalable, AI-enhanced automation, making decision-making more precise and efficient.
- Continuous operational improvement, where AI-driven insights drive ongoing optimisation.

Control rooms are evolving from reactive monitoring centres to proactive, intelligent hubs of decision-making. By leveraging real-time Digital Twin technology, terminals gain acute visibility into inefficiencies, unlocking a new era for port and logistics operations.

FIG 2. Augmented Troubleshooting diagram

ABOUT THE AUTHORS

Dr. Oscar Pernia holds an Industrial Engineering PhD, specialising in algorithm design and Simulation applied to marine operations optimisation. He has more than 20 years of international experience in container shipping, covering technology solutions and associated integrations across all processes in the ocean supply chain, with a specific focus in Ports & Terminals.

Francisco Blanquer is a Spanish civil engineer with extensive experience in the industrial sector, enabling him to lead complex multidisciplinary projects. Over the past 16 years, he has developed functions of innovation and development engineer in the port sector, managing the greenfield projects, introducing technologies (as LNG for port equipment or BigData), and disseminating the digital culture in their terminals. In the last 5 years, he has spearheaded BigData and decarbonisation projects for CMA CGM while supporting the container terminal industry as Chair Operations Council of the Terminal Industry Committee 4.0.

Nasser Ben Othman is a French Mechanical engineer who has served the terminal and port industry since 2012. He is currently serving as the Digitalization Manager at CMA CGM. With over a decade of experience, he has played a pivotal role in driving digital innovation and enhancing operational efficiency. Nasser is recognised for his strategic vision and methodical approach, enabling him to successfully navigate complex challenges. His expertise in digitalisation has been instrumental in propelling business units forward, ensuring sustained success. Nasser's commitment to leveraging technology and his proactive nature make him a valuable asset to the industry.

Hein Chetcuti is a seasoned expert in the container terminal industry, bringing over 20 years of experience in technological innovation and operational efficiency. With a strong background in digital transformation, he has been instrumental in designing, developing, and deploying mission-critical systems, including advanced Business Intelligence tools that optimise terminal performance. Hein has extensive experience engaging with diverse industry stakeholders, driving strategic innovation, and shaping the future of container terminal operations. He holds a BSc from

the London School of Economics, an MSc from Royal Holloway, and an MPhil from Universidad Católica de Murcia. Currently, he is pursuing a doctorate with a research focus on innovation in container terminals, further solidifying his leadership in the industry.

John Alvarez is an experienced professional in the maritime industry, currently serving as the R&D Director at Fenix Marine Services. With a rich history of innovating and delivering cutting-edge technical solutions, John has a deep understanding of both operational and business challenges. He has successfully implemented technologies to enhance efficiency, such as automating container scanning for rail imports. John has played a pivotal role in introducing advanced automation systems and optimising operations, contributing to his company's status as the world's first fully automated terminal. His dedication to leveraging technology and improving processes makes him a valuable asset to the industry.

ABOUT NEXTPORT.AI

NextPort, as Technology and Innovation spin-off of Moffatt & Nichol, provides technology solutions for Ports and Terminals. They partner with customers to make data connectable and useful, driving digitalisation to enhance efficiency, safety, sustainability and resilience. Their 360 Operational Digital Twin solution connects processes, data, and systems.

NexPort is contributing to transform the maritime industry with AI technology and data-driven decision-making.