TIC4.0

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White Paper Summary:

Terminal Automation Topology according to IEC62264 (ISA-95) & Definitions of Automation Levels

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This paper is based on a full publication that provides more detailed insights into the topic. To access the complete material, please refer to this **LINK**.

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1. Introduction

The TIC4.0 Whitepaper on Terminal Automation presents the industry's roadmap toward a unified, interoperable framework for automating container terminals. While automation can significantly improve efficiency, safety, and sustainability, progress has been slowed by fragmented technologies and inconsistent data models. TIC4.0 addresses this by serving as a neutral, vendor-agnostic body that develops shared data semantics, functional hierarchies, and process models to enable scalable and repeatable automation.

The current phase operationalizes these concepts through a Task Force on Terminal Automation and three Working Groups focusing respectively on:

1. **Mapping end-to-end terminal processes and automation impacts;**
2. **Defining consistent system-to-system information flows;**
3. **Extending TIC4.0's semantic model with precise definitions for automation workflows.**

A key deliverable will be a TIC4.0 Automation Appendix — a standard reference for tenders, helping operators and vendors design and procure automation systems based on a harmonized functional and data framework.

Despite growing adoption of automated and semi-automated terminals, significant challenges remain: high capital costs, long payback periods, legacy infrastructure, fragmented IT/OT systems, and limited interoperability, especially at the interface and process alignment levels. Workforce reskilling, social acceptance, regulatory constraints, and cybersecurity also pose major hurdles. Overcoming these barriers requires shared standards that align business, operational, and control layers.

Creating a framework for Terminal Automation - Using IEC 62264 (ISA-95)

To fill this structural gap, TIC4.0 proposes adapting the IEC 62264 (ISA-95) standard — widely used in manufacturing for enterprise–control system integration — to the port environment. This framework defines standardized functional levels (from business planning to physical process control), data objects, and workflows that ensure interoperability between IT and OT systems while remaining technology-agnostic. Its application in other industries (mining, pharma, oil & gas, SMEs) has proven its flexibility and scalability, making it an ideal foundation for port automation.

Within terminals, the adapted model introduces clear functional levels:

1. **Level 5: Business Intelligence (strategic insight and analytics)**
2. **Level 4: Business Planning & Logistics (order management, billing, planning, resource forecasting, maintenance)**
3. **Level 3: Operations Management (scheduling and coordination)**
4. **Level 2: Supervision & Control (real-time dispatching and monitoring)**
5. **Level 1–0: Machine control, sensors, and physical execution**

A successful implementation depends on balancing standardization with flexibility. The adapted model emphasizes three key attributes:

1. **Compatibility – integration with existing and legacy systems, both in greenfield and brownfield contexts.**
2. **Flexible Decision-Making – allowing different levels of automation to distribute operational authority according to the philosophy of the individual terminal.**
3. **Future Development – scalability to support emerging technologies, decentralized decision-making, and autonomous operations.**

By adopting this framework, TIC4.0 aims to reduce risk, improve interoperability, shorten implementation times, and create a sustainable pathway for terminal automation aligned with global industrial standards. Cybersecurity, in turn, shall be taken into account when designing interfaces, systems and other aspects of an automated terminal, for example IEC 62433. However, as a final note, please bear in mind that is not in the scope of this Task Force/White Paper to establish cybersecurity requirements or divisions; we think that each organisation/port shall independently decide on systems segmentation/compartmentalization.

TIC4.0 provides a neutral, industry-wide framework that standardizes data, functions, and processes to enable scalable and interoperable terminal automation.

By adapting the IEC 62264 (ISA-95) model to ports, it aligns business, operational, and control layers under a proven, technology-agnostic structure that eases integration, reduces risk, and supports progressive automation.

2. Challenges for Automation in Terminals

Terminal automation is advancing rapidly as ports seek greater efficiency, safety, and sustainability, with semi- and fully automated terminals becoming increasingly common, particularly in new greenfield projects. The trend is driven by the integration of digital technologies such as IoT, artificial intelligence, predictive analytics, and real-time monitoring, which allow for more reliable planning, optimization of vessel calls, and predictive maintenance.

At the same time, automation is closely linked to environmental goals, with electric equipment and energy optimization helping ports reduce their carbon footprint. The shift is also reshaping the workforce: operational jobs are giving way to more technical and data-oriented roles, requiring reskilling and careful management of social impacts. Taken together, these tendencies point to a growing market for automation solutions, with operators pursuing 24/7 operations and more consistent performance to handle congestion and global trade pressures.

Yet significant challenges remain. The most pressing is the high cost of automation, with long payback periods that make investment difficult for smaller or less busy terminals. Many facilities must also contend with legacy infrastructure and fragmented IT systems, which complicate integration and create data silos that undermine visibility and interoperability.

Operational risks during the transition are another concern, as converting a manual or semi-automated process to a semi-automated or fully automated one can disrupt throughput and efficiency. Moreover, automation of terminals works best under predictable conditions, but ports must often deal with irregularities such as weather, equipment failures, or customs delays, which demand flexible exception-handling.

Beyond the technical dimension, workforce adaptation and labor relations present persistent obstacles, as unions and employees express concerns about job security. These issues are compounded by regulatory hurdles, safety certifications, and the growing need to secure increasingly digital operations against cyberattacks. Finally, terminals must ensure that automated systems are robust against environmental stresses and supported by adequate electrification and grid infrastructure.

In short, while terminal automation is poised to transform global port operations through digitalization, sustainability, and greater reliability, its widespread adoption will depend on overcoming steep financial, technical, and social barriers, and on developing shared standards to reduce risks and ensure interoperability.

Lack of standardized integration structure

Despite the growing momentum behind **terminal automation**, there is **still no standardized structure or reference model** that defines how different functions should be integrated and interact within a terminal environment. Each terminal—depending on its size, geography, and operational philosophy—adopts its own interpretation of automation, leading to **fragmented architectures and inconsistent functional hierarchies**. As a result, projects remain largely bespoke, with limited potential for reuse or scalability. What proves efficient in one terminal often requires substantial redesign in another, increasing costs, complexity, and implementation times.

The absence of a common integration structure is particularly evident in brownfield environments, where existing assets, workflows, and digital tools were not originally conceived for automated coordination. In practice, the **lack of standards does not allow to copy solutions (functions or functional logics) from one project to another**, even if two terminals are performing in similar ways or have similar processes. This also hinders synergies.

The **lack of shared definitions** of where one function ends and another begins—whether related to planning, control, or execution—creates ambiguity and dependency on proprietary interpretations. This fragmentation **undermines the ability to harmonize data flows and operational behaviour across the sector.**

To address this, the industry should **avoid "re-inventing the wheel"** and instead **draw inspiration from reference models** that have already proven effective in other industrial domains. The international **electrotechnical standard IEC 62264 (equivalent to the North American ISA-95)** provides a structured approach for defining the interaction between enterprise and control domains.

By **establishing hierarchical levels and standardized information exchanges,** it enables consistent communication between functional layers—business, operations, and equipment. Translating these principles into the port environment could **lead to a generic reference architecture for functional and system integration, serving as a foundation for TIC4.0's harmonization efforts** while maintaining flexibility across both greenfield and brownfield implementations.

3. IEC 62264 Description

IEC 62264, based on the North American ISA-95 standard, is an international standard for enterprise–control system integration. It establishes common models, terminology, and interfaces so that manufacturing systems (like Manufacturing Execution Systems (MES), Supervisory Control And Data Acquisition (SCADA) or shop-floor automation) and enterprise systems (such as ERP, logistics, and planning) can work together more seamlessly. The standard is widely used across industries to support Industry 4.0, digital manufacturing, and IT/OT convergence.

Its main objectives are to:

- **Facilitate interoperability by defining standard object models, attributes, and transaction structures.**
- **Reduce risk, cost, and errors when integrating business systems with manufacturing operations.**
- **Provide a common vocabulary and activity models for engineers, IT staff, and business stakeholders.**
- **Support modular, scalable architectures that evolve with technology.**

The standard is structured into several parts, each addressing a different aspect of integration:

Part 1 – Models and Terminology: defines the scope, terminology, and functional boundaries between enterprise and control systems.

Part 2 – Object Model Attributes: specifies standard data objects and attributes exchanged between systems.

Part 3 – Activity Models: describes the workflows and functions of manufacturing operations.

Part 4 – Manufacturing Operations Management (MOM) Integration: refines object models for integration within manufacturing operations management.

Part 5 – Business-to-Manufacturing Transactions: details the types of transactions between enterprise systems and manufacturing systems.

Part 6 – Messaging Service Model: defines abstract messaging services to support information exchange in a technology-agnostic way.

In practice, IEC 62264 is often implemented using B2MML (Business to Manufacturing Markup Language), which translates the models into XML schemas, or through Open Platform Communications (OPC) Unified Architecture (UA) information models, which embed the standard's concepts into industrial interoperability frameworks.

The **areas of application** include:

- Integration of shop-floor automation (PLCs, SCADA, MES) with enterprise IT systems (ERP, SCM).
- Process, batch, and discrete manufacturing industries with complex operations.
- Industry 4.0 and digital factory initiatives where standardized data exchange and system interoperability are crucial.
- Projects requiring a clear mapping between level 3 (manufacturing operations) and level 4 (enterprise planning) in the automation hierarchy.

IEC 62264 (ISA-95) standard defines the following hierarchical division. This framework divides industrial activities into five levels, ranging from business planning to the physical process:

1. **Level 4: Business Planning and Logistics**

Level 4 defines the functions that manage and coordinate the organization as a whole. It establishes objectives, allocates resources, and sets the conditions under which operations take place. Information from this level guides lower levels, ensuring alignment between enterprise goals and operational execution.

2. **Level 3: Operations Management**

Level 3 coordinates and oversees the execution of operational activities within a facility or network. It manages resources, monitors progress, and ensures that operations are carried out according to the objectives and constraints defined at higher levels.

3. **Level 2: Supervision and Control**

Level 2 manages the real-time supervision and control of processes and assets. It executes operational instructions, maintains stability and safety, and provides continuous feedback on process status and performance to higher levels.

4. **Level 1: Sensing and Actuation**

Level 1 includes the devices and components that measure and influence the physical process. Sensors, actuators, and other field devices collect data and execute commands that enable automated control.

5. **Level 0: Physical Process**

Level 0 represents the actual physical activities taking place in the field — the transformation, movement, or interaction of materials, energy, or information that the higher levels monitor and control.

4. Why IEC 62264 was chosen

Interoperability is key for success

Ensuring **interoperability between systems, regardless of the specific case or region, is critical for modern industrial environment**ts. Current "As-Is" setups often face limitations, as direct communication between the OT (Operational Technology) level and the Planning level becomes unfeasible due to firewalls and other security barriers, leading to challenges in error and exception handling. The separation of Information Technologies (IT) and OT technologies[1] is increasingly enforced by regulatory obligations, particularly in critical infrastructure sectors (CRITIS).

To address this, IT and OT require a well-defined interface that enables reliable conversion and integration between the two domains. The IEC62264 (ISA-95) standard serves as a foundational framework in this context, providing guidelines for both cyber security and automation, and facilitating structured, secure communication across IT and OT systems.

Benefits of aligning with IEC 62264 (ISA-95)

Aligning with a standard like IEC 62264 (ISA-95) brings the following advantages

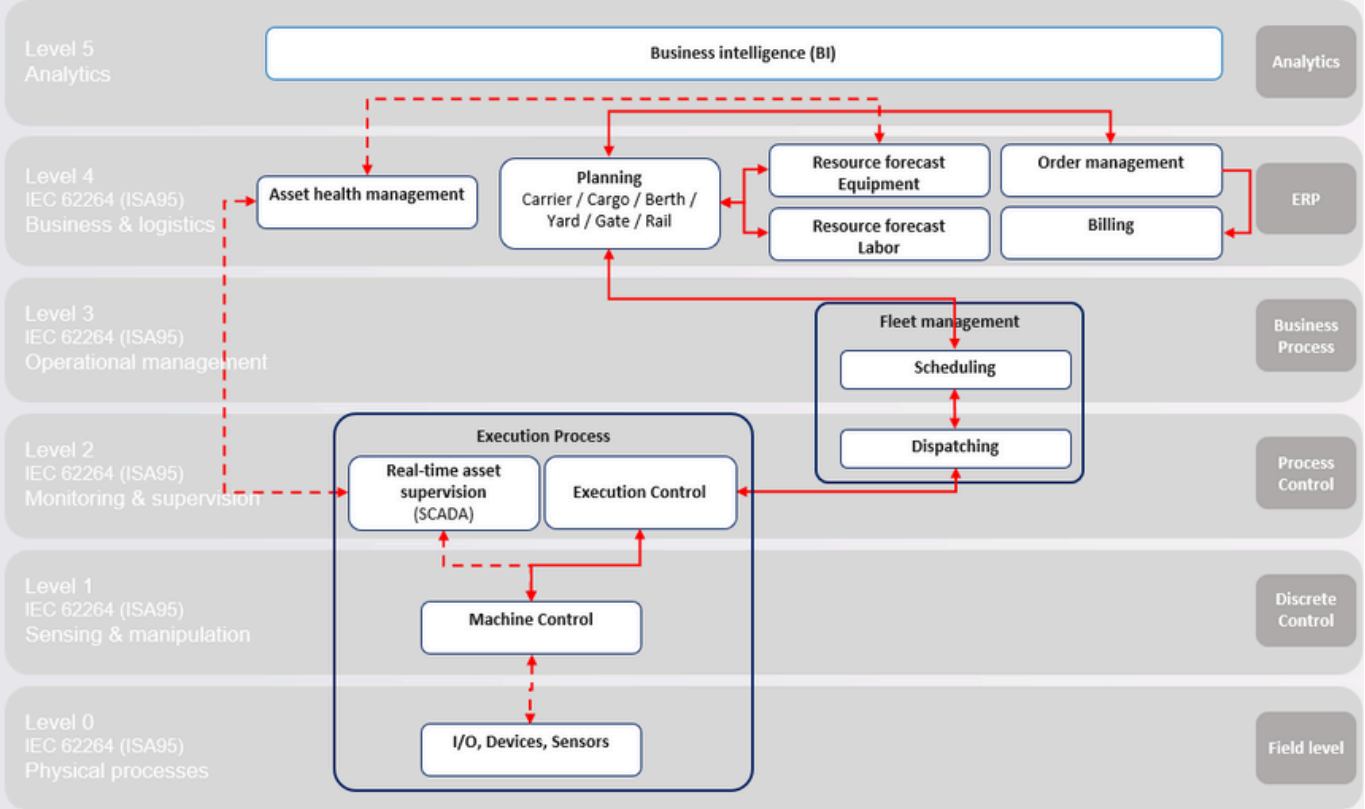
- interoperability with proven standard
- future implementations will be easier → faster turnaround and implementation times
- terminal automation in line with proven standard for integration of business and
- control systems

Lastly, an alternative framework: **Purdue model, based on IEC 62264 (ISA-95),** can also be used as an alternative to the standards. The Purdue Model and IEC 62264 (ISA-95) are complementary frameworks that guide industrial digitalization and system integration. The Purdue Model provides a hierarchical reference architecture, clearly separating OT (Operational Technology) and IT layers to enhance security, define responsibilities, and structure industrial processes from sensors and control systems up to enterprise systems. IEC62264 (ISA-95), in contrast, focuses on standardizing information exchange and workflows between manufacturing operations and enterprise management, particularly MES and ERP systems.

While Purdue defines where systems sit, IEC62264 (ISA-95) defines how information flows between them, making the combination of both frameworks essential for achieving secure, interoperable, and efficient industrial operations.

[1] *Hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events, as per IEC 62443-1-1:2013, Clause 3.1.68 (co-published as ISO/IEC 62443)*

5. Adapting IEC 62264 to port terminals



Topology acc. to IEC62264 (ISA-95)

Modern port operations rely on a structured, hierarchical approach to manage complex systems, from the physical processes on the ground to high-level business decision-making. This hierarchy, often represented in levels 5 through 0, ensures that every aspect of the operation, ranging from field devices and sensors, through process control and fleet management, to enterprise resource planning and analytics, is clearly defined, coordinated, and optimized. By mapping responsibilities and data flow across these levels, organizations can achieve seamless integration, improve operational efficiency, and leverage real-time insights to make informed strategic decisions.

Modern port operations use a hierarchical system to integrate physical processes, management, and analytics, enabling efficiency and informed strategic decisions

Business Intelligence

In the context of port terminals, an **additional layer — Level 5: Business Intelligence — can be introduced above the traditional IEC 62264 (ISA-95)** hierarchy. This level encompasses the systems and functions dedicated to aggregating, analyzing, and interpreting information from all other levels to support strategic decision-making, performance monitoring, and long-term optimization. While it does not directly control operations, it **provides insights that guide policy, planning, and continuous improvement across the entire terminal ecosystem.**

Interface to the Terminal Customer

Although it does not intervene directly in operations, BI provides the analytical foundation for informed decision-making across the terminal ecosystem.

Within Level 4 (Business and Logistics), the **primary interface between the terminal and its customers is established through Order Management and Billing**. Together, these functions translate commercial demand into executable operational plans while ensuring accurate financial reconciliation.

- **Order Management** coordinates the **exchange of service requests with shipping lines, freight forwarders, and inland operators.** It validates bookings, captures cargo and service information, and keeps order status aligned with real-time execution.
- **Billing** consolidates **operational data into financial transactions, applying contractual rates and issuing invoices.** This ensures a transparent link between executed services and commercial charges.

Core Functions to manage a terminal

At Level 4 (Business and Logistics), the **Planning Module and Resource Forecasting functions form the backbone of operational coordination in a port terminal.** Their role is to translate commercial and logistical objectives into structured operational frameworks, ensuring that resources, capacities, and infrastructure are aligned with anticipated cargo flows.

- **Planning** defines **upcoming operational plans across vessel, cargo, yard, berth, gate, and rail activities**. It integrates customer requirements with resource availability and terminal constraints to establish a coherent operational baseline.
- **Resource Forecasting (Equipment and Labor)** anticipates **future equipment and workforce demand by combining planned activities with historical patterns.** This enables informed decisions on asset deployment and workforce management.

Health and Maintenance

Within Level 4 (Business and Logistics), **Health and Maintenance play a critical role in ensuring the terminal's operational continuity.** These supporting functions safeguard the performance, availability, and longevity of terminal assets by monitoring their condition, scheduling preventive maintenance, and carrying out timely repairs.

By aligning maintenance tasks with operational requirements, **Health and Maintenance act as the bridge between long-term asset management and day-to-day reliability,** helping the terminal operate safely, efficiently, and without unnecessary interruptions.

Fleet Management, supported by Scheduling and Dispatching, ensures that planned activities are translated into efficient, real-time equipment deployment and task execution across the terminal.

Fleet Management

Fleet Management ensures that a **terminal's mobile equipment is deployed efficiently and on time across all operational areas.** By linking planning decisions with real-time activity, it translates operational requirements into concrete equipment assignments and task execution.
Within this framework, two key functions enable the transition from planning to execution:

- **Scheduling**

Operating primarily at Level 3 (Operations Management), **Scheduling converts planning outputs—such as work queues, work packages, and work instructions—into executable, time-bound job sequences.** It ensures that planned activities are organised into feasible workflows consistent with resource availability, operational constraints, and priority rules.

- **Dispatching**

Dispatching executes the job instructions produced by Scheduling in real time. It assigns and confirms the use of cargo-handling equipment (CHE), issues and monitors job tasks, validates operational feasibility, and reports progress and exceptions. As the **link between Scheduling and Execution Control,** Dispatching ensures that planned work is carried out accurately and efficiently.

Together, these functions form the **operational backbone** that connects strategic planning with real-time performance across the terminal.

Execution Process

The **Execution Process** covers the **systems that directly perform terminal operations**, converting operational instructions into coordinated physical actions. At Level 2, Asset Supervision (SCADA) and Execution Control manage real-time activity by supervising equipment, distributing operational data, and ensuring tasks are executed safely and within defined parameters. At Level 1, Machine Control governs the direct operation of cranes, vehicles, and other handling equipment, executing movement commands and interpreting sensor inputs to guarantee precision and safety. Together, **these layers form the essential control chain linking operational planning to on-the-ground execution.**

At Level 0 (Physical Process), I/O modules, devices, and sensors form the direct interface between control systems and the physical environment. They capture process variables, transmit real-time signals, and execute low-level actions such as actuation, positioning, and status signalling.

Together, these components **anchor the terminal's operational chain by linking system logic to the real-world mechanisms that move cargo and operate equipment**. Organising terminal functions across structured levels—from enterprise systems down to field execution—provides a consistent framework for integration, data flow, and interoperability. **While not prescribing specific technologies or responsibilities**, this **layered architecture enables terminals to introduce automation progressively,** ensuring that business intent is coherently connected to operational reality within a scalable and coordinated environment.

6. Ensuring successful adaptation in the real-world

Balancing Standardization and Practical Applicability

The refined framework—developed through extensive consultation with industry experts—must **balance standardization with real-world applicability** across highly diverse terminal environments. Three guiding attributes underpin this approach: compatibility with existing solutions, flexibility to support different operational philosophies, and a structure that enables future development while remaining a stable standard. Together, **these principles support gradual adoption, interoperability, and long-term sustainability.**

Compatibility

Compatibility ensures that the model can integrate with the many system types, automation levels, and legacy infrastructures present across global terminals. Rather than prescribing rigid implementation details, **the framework defines general layers, functions, and information elements that can map to different technological maturities**—from manual to fully automated operations. This adaptability avoids the pitfalls of overly prescriptive standards and allows terminals to align under a shared architecture with minimal disruption, similar to how small design tolerances make power plug types interoperable. This approach preserves interoperability while enabling terminals to maintain their preferred workflows, system architectures, and operational boundaries.

Decision Making

Decision-making processes vary significantly across terminals. To reflect this reality, the framework does not impose where or by whom each decision must be made. Instead, it supports varying operational philosophies by defining the information needed for autonomous or coordinated decisions at any layer. Emerging "decision modes"—such as mandatory decisions, proposals, and pass-through information—help classify the degree of autonomy involved and form part of TIC4.0's evolving semantic model. This flexibility ensures that functions like Planning, Scheduling, or Dispatching can take responsibility for decisions according to each terminal's setup, while still maintaining system consistency and interoperability, and allowing automation to evolve progressively.

Future Development

Future development focuses on ensuring that the model remains scalable as new technologies emerge. With increasing computational power and more capable edge devices, decision-making will increasingly occur closer to the equipment. The framework anticipates this shift by keeping architectural layers stable while allowing intelligence to move dynamically across them. By defining robust information structures rather than fixed behaviours, the model ensures long-term consistency and supports the transition from centralized control to more distributed or autonomous systems.

7. Conclusions and next steps

The adaptation of IEC 62264 (ISA-95) to port terminals presented in this White Paper establishes a coherent, industry-wide reference model capable of guiding the next decade of terminal automation. By defining clear functional layers—from business intelligence to field execution—and by aligning them with shared information structures, the framework resolves long-standing integration gaps between IT and OT, reduces dependency on bespoke system designs, and provides a common vocabulary for operators, vendors, and technology providers. The principles of compatibility, flexible decision-making, and future-proof scalability ensure that the model can be applied across manual, semi-automated, and fully automated environments, supporting both brownfield and greenfield deployments.

With this foundation, terminals can introduce automation in a progressive, low-risk manner while maintaining interoperability across heterogeneous systems and evolving technologies. By anchoring automation efforts in a proven, technology-agnostic standard, TIC4.0 equips the industry with a stable and scalable architecture that enables consistent data flows, clearer functional boundaries, and more robust operational coordination.

Lastly, this framework provides a practical pathway toward safer, more efficient, and more sustainable port operations—supporting a harmonized global ecosystem where automation can flourish without sacrificing flexibility, innovation, or operational diversity.

Future Development

While the IEC 62264 (ISA-95) framework provides a shared foundation for terminal automation, the next phase will focus on advancing interoperability and operational efficiency. Key priorities include formalizing “decision modes,” defining critical functions—especially planning and execution control—and establishing robust, technology-agnostic interfaces between them.

Particular emphasis will be placed on connecting scheduling with planning and dispatching with execution control, while continuously refining all functional definitions. These steps will guide the industry toward a coherent, step-by-step approach to integrated, seamless terminal operations under the TIC4.0 framework