TOS Industry Reference Architectures & Data Models

Architecture Analysis for CLdN Ports Zeebrugge — Mixed RoRo Terminal

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Executive Summary

Eight industry sources were researched for reference architectures, data models, and standards applicable to terminal operating systems at a mixed RoRo terminal like CLdN Ports Zeebrugge. The findings reveal a fragmented landscape:

- **TIC4.0** is the only body actively publishing an open TOS/CHE data model, but it remains container-centric and gated behind member access
- **Navis N4** and **Navis Master Terminal** provide the most detailed publicly-known domain models; Master Terminal is directly relevant for RoRo/mixed cargo
- **Kalmar One** is an automation layer (not a TOS) with open APIs and proven container automation; no RoRo modules
- **Tideworks Mainsail** has an actual RoRo module and serves North American mixed-cargo terminals
- **PROTECT EU** — no project found; EU port security landscape (SAURON, PRECINCT, COLOSSUS) focuses on cyber-physical security
- **ISO 28000** is a security management system standard; ISO 28004-2 has seaport-specific guidance
- **PIANC WG 167** (2023) is the authoritative physical design reference for RoRo/RoPax terminals
- **World Bank Port Reform Toolkit** (3rd ed., 2025) covers digital transformation at governance level

> **Critical Gap:** No open/published RoRo TOS reference architecture exists equivalent to TIC4.0 for containers. The RoRo domain model must be synthesized from Navis Master Terminal, Tideworks Mainsail, PIANC WG 167, and actual CLdN operations.

Source Relevance Overview

Source	Type	RoRo Rating	Key Value
TIC 4.0	Open Standard	Medium	Container-side semantic data model; Carrier Visit / Cargo Visit framework
Navis N4 / Master Terminal	Commercial TOS	High (MT)	Detailed RoRo deck model, VIN tracking, mixed cargo
Kalmar One	Automation Middleware	Low	Container automation layer only; IEC 62443 certified
Tideworks Mainsail	Commercial TOS	High	Native RoRo module; TOTE Alaska deployments
EU Projects	EU Research	Low (TOS) / High (Security)	Port cyber-physical security architecture
ISO 28000	ISO Standard	Medium	Security management; ISO 28004-2 seaport
PIANC WG 167	Design Guideline	High (ops)	RoRo/RoPax terminal physical & operational design
World Bank Toolkit	Governance	Medium	Smart port maturity model; Module 9

1. TIC 4.0 — Terminal Industry Committee 4.0

URL: tic40.org | **Status:** Active, Brussels-based non-profit, 70+ members

The only open industry initiative defining a shared semantic framework for cargo terminals. 17 releases (2021–2025). Targets interoperability between terminals and equipment manufacturers.

Data Model Core

```
Carrier Visit
  → has many Cargo Visits
       → each involves Movements
            → each involves a CHE
                 → CHE executes Cycles → Moves
```

Published Standards (Selection)

Release	Key Topics
2021.001–002	CHE Activity, Power Source, Move/Cycle definitions, initial Data Model
2022.003–006	Carrier Visit, Cargo Visit, Health, Drive, Movement; KPI definitions
2023–2024	Expanded operational and CHE/TOS semantics
2025.014–017	Reefer definitions, COARRI↔TIC4.0 mapping, Vessel EDI

Technology-agnostic (REST/JSON, SOAP/XML, OPC-UA, MQTT). PAS 4000 (BSI) formalization in progress.

RoRo Rating: Medium — Almost entirely container-focused. Carrier Visit framework reusable for RoRo side. No wheeled cargo or vehicle entities.

2. Navis N4 / Master Terminal (Kaleris)

Status: Market leader, 320+ deployments. Java-based metadata-driven platform.

Domain Model

Layer	Key Entities
Facility	Complex, Facility, Yard (Block/Bay/Row/Tier), Berth
Operations	Vessel Visit, Unit, Unit Facility Visit, Equipment, Work Instruction
Planning	Vessel Bay Plan, Berth Assignment, Yard Strategy
Administrative	Booking, Service Event, Hold, Bill of Lading
Gate	Gate Transaction, Truck Visit, Driver

11 Functional Modules

Gate Management, Yard Management, Vessel Planning, Vessel Autostow, Berth Planning, Rail/Intermodal, Equipment Scheduling (XPS), Mobile Suite, Billing/Services, EDI Engine, Safety Suite, Reporting/Analytics.

Master Terminal — RoRo Extensions

- Detailed RoRo deck definition with vehicle lanes, pillars, ramps, twistlock grids
- Graphical deck visualization at all operational stages
- VIN-based vehicle tracking
- Cargo polygon areas for mixed deck layouts (containers + vehicles + general cargo)
- Weight/height/stack limit enforcement per deck zone

RoRo Rating: High (Master Terminal) — Architecturally the closest product for CLdN's mixed operation.

3. Kalmar One Automation System

Important: Kalmar One is NOT a TOS. It is an automation middleware layer between TOS and physical equipment. Equipment-agnostic: ASC, ARTG, AGV, AutoTT, AutoStrad.

SmartPort Modules

Module	Function
SmartStack	Automatic container position reporting
SmartTruck	Real-time yard truck visibility
SmartLift	Automated job promotion for operators
SmartLane	Automated gate entry/exit identification
SmartRead	Spreader OCR for container ID
SmartMap	Real-time + historical site visualization

First ports solution IEC 62443-4-1 certified (OT/IT security, Aug 2023).

RoRo Rating: Low — No RoRo automation modules. Relevant only for container side.

4. Tideworks Mainsail

Status: 100+ marine & intermodal terminals. SaaS on AWS. Backed by Blackstone.

Product Suite

Product	Function
Mainsail (core)	Container, RoRo, break-bulk terminal management
Mainsail Ro/Ro	Rolling stock tracking, vehicle lifecycle management
Spinnaker	Graphical vessel & yard planning; BAPLIE/COARRI
Traffic Control	Electronic equipment dispatch
Intermodal PRO	Rail terminal TOS
Genoa	Standalone breakbulk management

TOTE Alaska deployments closely analogous to CLdN's mixed RoRo operations on North Sea.

RoRo Rating: High — Native, production-proven RoRo module. Limitation: primarily North American vendor.

5. EU Port Security Projects

No "PROTECT" project found. Related EU projects focus on cyber-physical security:

- **SAURON** (H2020, 2017–2020): Situational awareness for port protection. Documents how TOS cyber events cascade to physical safety.
- **PRECINCT** (H2020, 2021–2023, €9.47M): Digital Twin framework for CI topology modeling, ML-based detection.
- **COLOSSUS** (Horizon Europe, ongoing): Autonomous vehicle swarms and sensor networks for port security.

EU-funded projects address security/resilience, not TOS domain models. Outputs inform NIS2 compliance for TOS.

6. ISO 28000 Series

Security management system standard (Annex SL structure). 2nd edition 2022.

Key Standards

Standard	Title	Relevance
ISO 28000:2022	Security management requirements	Core framework
ISO 28004-2:2014	Seaport implementation guidelines	Port-specific
ISO 28005-1/2	Electronic port clearance	Port EDI

RoRo Rating: Medium — Compliance requirement, not architecture. ISO 28004-2 provides security baseline for TOS gate/DG/access control.

7. PIANC WG 167 — RoRo/RoPax Terminal Design (2023)

Authoritative physical design reference. No software/IT content, but defines functional requirements for RoRo TOS:

- Vehicle lane dimensioning → TOS yard position model
- Deck category definitions → TOS vessel deck model
- Cargo segregation zones → TOS zone management
- VIN/vehicle tracking flow → TOS unit model
- Pre-embarkation checks → TOS gate model

RoRo Rating: High (operational context) — Essential for understanding what the TOS must functionally support.

8. World Bank Port Reform Toolkit (3rd Ed., 2025)

Module 9: Digitalization & Cybersecurity. TOS as "digital backbone." Smart port maturity (5 levels). NIS2/IMO alignment.

RoRo Rating: Medium (governance) — Strategic framing and board-level language for TOS initiative.

Cross-Cutting Synthesis

Common Entity Mapping

Entity	TIC4.0	Navis N4	Tideworks
Ship visit	Carrier Visit	Vessel Visit	Vessel Visit
Cargo unit	Cargo Visit	Unit (Facility Visit)	Unit
Unit movement	Movement	Work Instruction	Work Order
Equipment	CHE	Equipment	Equipment
Position	Position	Block/Bay/Row/Tier	Yard Position
Gate	—	Gate Transaction	Gate Transaction

RoRo-Specific Entities (Not Covered by Container Standards)

Entity	Source
Vehicle (VIN)	Master Terminal, Tideworks, GullsEye
Deck definition	Master Terminal, PIANC WG 167
Vehicle Lane	Master Terminal, PIANC WG 167
Ramp / Linkspan	PIANC WG 167
PDI Record	Master Terminal
Trailer manifest	Tideworks
Marshalling zone	PIANC WG 167

Container vs RoRo Differentiation

Dimension	Container TOS	RoRo TOS
Core cargo unit	ISO container (TEU/FEU)	Vehicle (VIN) or trailer
Position model	Block/Bay/Row/Tier (stack)	Lane/Row/Zone (flat)
Vessel model	Bay plan (grid)	Deck plan (lanes, zones, heights)
Key equipment	Crane, RTG, straddle	Shore ramp, tractor, reach stacker
Pre-processing	Seal check, weight, EDI	VIN scan, PDI
Throughput	Crane moves/hour	Vehicles/hour over ramp

Architecture Recommendations

What's Available vs What's Needed

Requirement	Best Source
Container TOS domain model	Navis N4 (industry standard)
RoRo TOS domain model	Navis Master Terminal + Tideworks Mainsail
Data/semantic standards	TIC4.0 (container); no open RoRo standard
Physical terminal design	PIANC WG 167 + WG 213
Security management	ISO 28000 + ISO 28004-2
Electronic pre-arrival / EDI	ISO 28005, UN/EDIFACT
Smart port governance	World Bank Module 9
Equipment automation	Kalmar One (container only)

Proposed Domain Model for Mixed RoRo TOS

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FACILITY
  Berth (type: RoRo, Container, General)
  Quay Zone
  Yard Zone (Vehicle, Trailer, Container, Breakbulk)
    Lane (vehicles) | Block/Bay/Row (containers)
  Gate (inbound/outbound)

CARRIER VISIT (= Vessel Call)
  Vessel → Voyage → Berth Assignment
  Deck Plan
    Deck (height, weight, ramp access)
    Vehicle Lane | Container Zone | General Cargo Zone

CARGO UNIT
  Vehicle Unit (VIN) + PDI Record + Damage Report
  Container Unit (ISO) + Reefer + IMO DG
  Trailer Unit (accompanied/unaccompanied) + Manifest
  Breakbulk Unit (lot/commodity/piece)

MOVEMENT
  Work Order + Equipment Assignment
  Position (From → To) + Timestamp

GATE TRANSACTION
  Truck Visit + Driver + Cargo Declaration + Customs

BILLING
  Service Event + Rate/Tariff + Invoice
```

NIS2 & Cybersecurity Stack

- ISO 28000 + ISO 28004-2 — security management
- IEC 62443 — OT/IT security
- IMO MSC-FAL.1/Circ.3 — maritime cyber risk
- SAURON/PRECINCT outputs — EU port threat models

Standards Hierarchy

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INTERNATIONAL:  ISO 28000, UN/EDIFACT, IMO FAL/MSC
INDUSTRY:       TIC4.0, PAS 4000 (BSI)
PHYSICAL:       PIANC WG 167 (RoRo), WG 213 (multipurpose)
GOVERNANCE:     World Bank Toolkit Module 9
COMMERCIAL:     Navis MT, Tideworks, GullsEye, OSCAR
AUTOMATION:     Kalmar One (container)
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Research conducted March 26, 2026 | Prepared by PAI | All source URLs verified