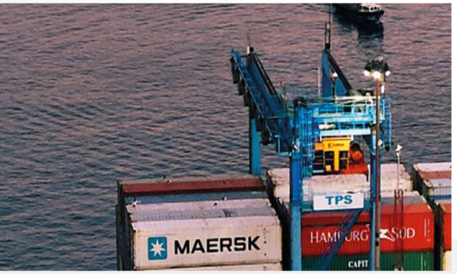

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The Future of Smart Ports, Global Tendencies Towards 2040

El Futuro de los Puertos Intelligentes: Tendencias Globales al 2040

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El Futuro de los Puertos Intelligentes: Tendencias Globales al 2040

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- By 2040, smart ports will likely have evolved from digitally connected terminals into **autonomous, predictive, low-carbon, and climate-resilient logistics ecosystems**. Competitiveness will depend not only on container-handling productivity, but also on the ability to coordinate ships, terminals, inland transport, energy systems, customs, communities, and digital platforms in real time.
- This forecast is not a prediction of one inevitable future. It is a scenario-based assessment based on current technological, regulatory, environmental, and operational trends. Most important external anchor is the IMO’s 2023 greenhouse-gas strategy, which calls for international shipping to reduce total GHG emissions by at least 70%—striving for 80%—by 2040 compared with 2008 (net-zero emissions targeted by or around 2050). Consequently, by2040, smart-port development will be inseparable from decarbonization.

The 2040 smart-port concept

By 2040, a smart port should be understood as:

- Interconnected maritime logistics ecosystem that uses real-time data, artificial intelligence, automation, clean energy, and collaborative governance to optimize cargo flows while improving safety, resilience, environmental performance, and social value.
- This definition extends the earlier idea of a smart port as a connected, sustainable, safe, and automated port. It also reflects the increasing importance of end-to-end integration: recent assessments describe AI systems that predict congestion and autonomous vessels moving from concept toward prototypes.

The principal change will be a shift:

- from **reactive operations** to predictive operations;
- from isolated terminal optimization to network-wide optimization;
- from fossil-fuel dependence to digitally managed clean-energy systems;
- from human-operated equipment to human-supervised autonomy;
- from efficiency alone to efficiency combined with resilience and sustainability.

Likely technological trajectory

Artificial intelligence as an operational (up to strategical) layer
Digital twins and simulation
Autonomous and remotely operated systems

Decarbonization and the energy-port nexus

- Ports as energy hubs
- Shore power and emissions management
- Carbon measurement and regulation

Autonomous ships and smart port calls
The port as a network platform
Resilience under climate and geopolitical uncertainty
Human capital and the future workforce
Cybersecurity, sovereignty, and digital trust

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Three likely scenarios

- **A: Coordinated smart-green transition**

Optimistic scenario: ports, shipping lines, regulators, and energy providers establish common standards. Clean fuels become available, port-call data are shared, automation improves safety, and digital platforms reduce congestion and emissions.

The port functions as an integrated maritime-energy-logistics ecosystem. Most efficient scenario, but requires high investment, international cooperation, and effective regulation.

- **B: Fragmented technological transition**

Major ports deploy advanced systems, but platforms remain incompatible. Large shipping companies and terminal operators capture most of the benefits, while smaller ports and logistics providers struggle to participate.

The result is technological progress without full network integration. Port productivity improves in selected locations, but supply-chain visibility remains incomplete and inequalities between regions increase.

- **C: Resilience-first maritime system**

Repeated climate, cyber, and geopolitical shocks lead ports to prioritize continuity over maximum efficiency. Ports invest heavily in redundancy, distributed energy, alternative routes, and secure local systems.

Automation and AI still expand, deployed cautiously. Emphasis not on most advanced technology, but on systems that can continue operating under disruption.

2040: The actual future will probably combine these scenarios. Major gateway ports may approach Scenario A, smaller or vulnerable ports may follow Scenario C, and global interoperability may remain closer to Scenario B.

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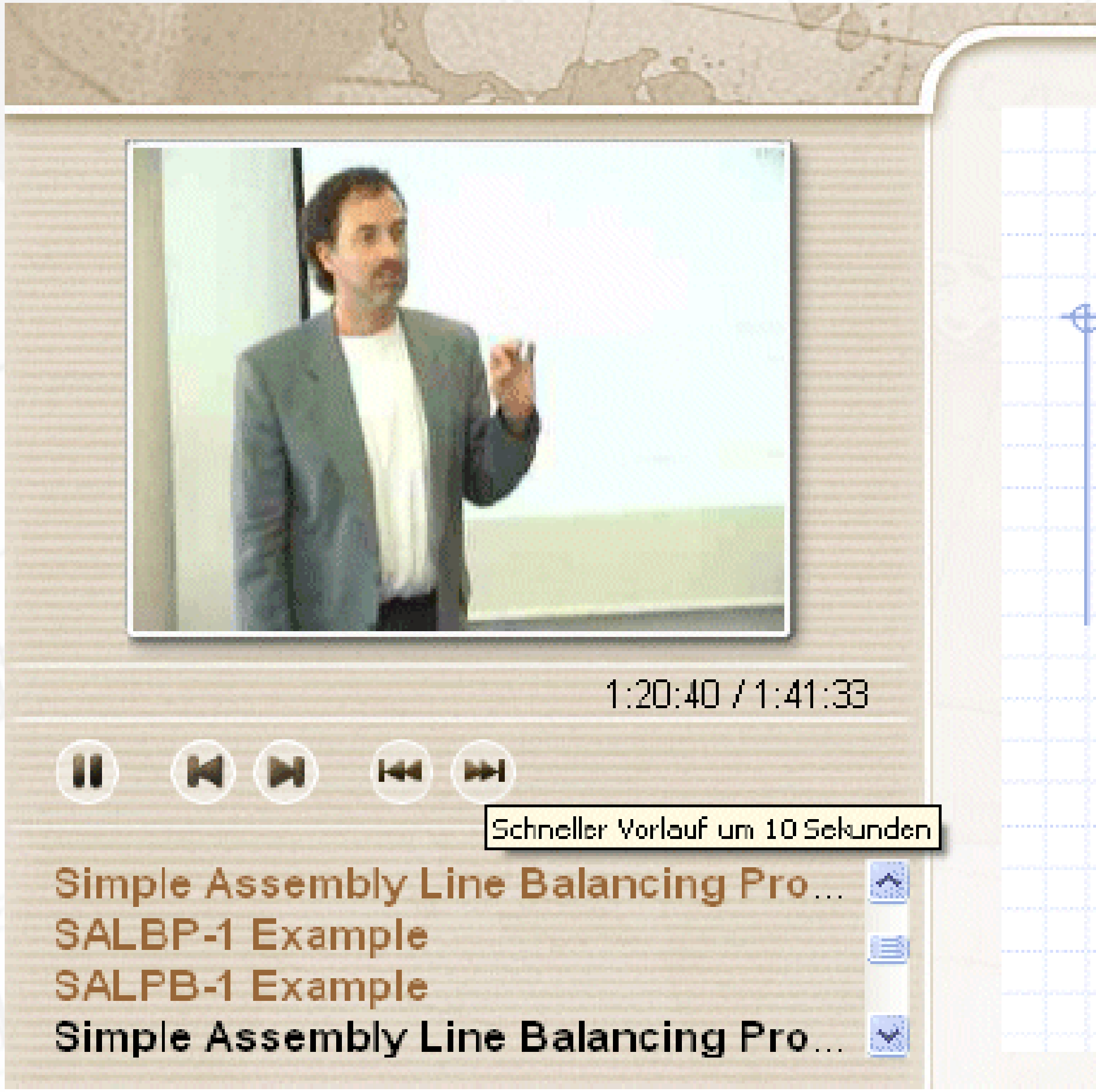
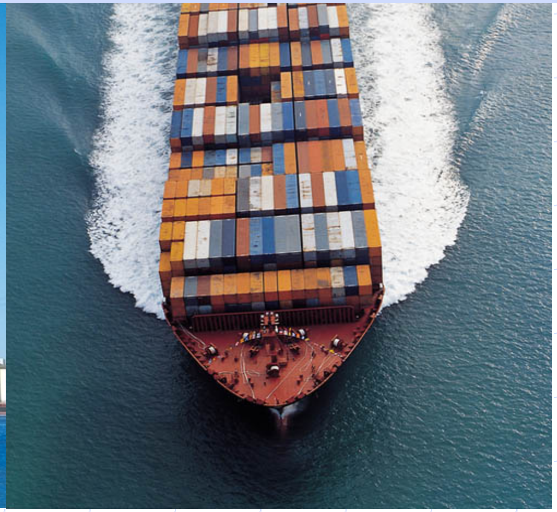
Live recordings of the lectures within a Web-based VLE



International Workshop on Risk Management in Port Operations, Logistics and Supply Chain Security, London, September 29th, 2006

Container Terminal Operations Under the Influence of Shipping Alliances



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Shanghai Jiao Tong University

UH

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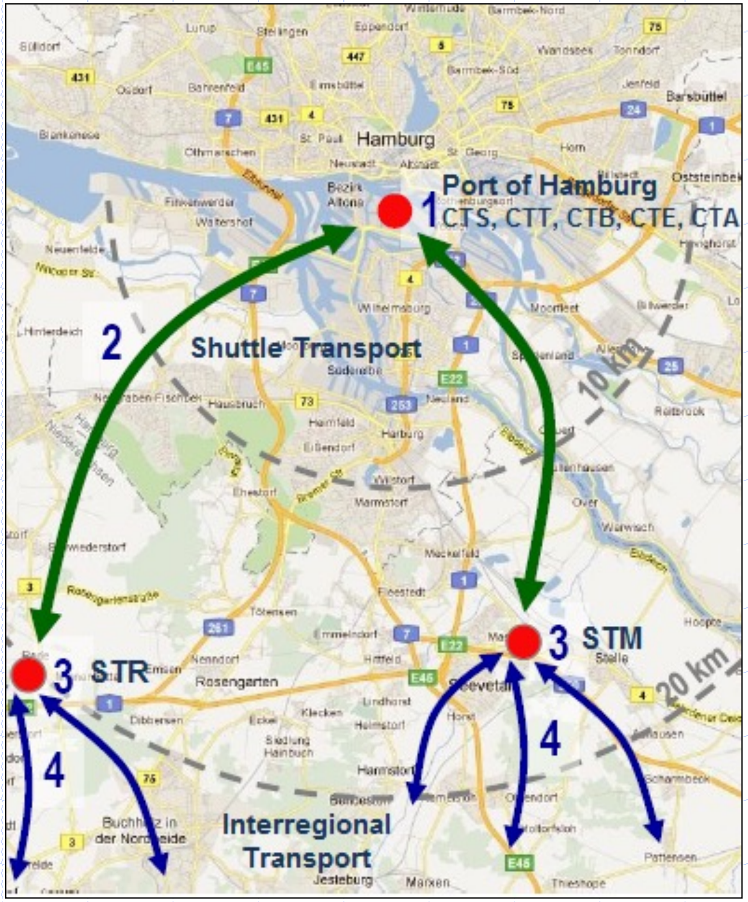
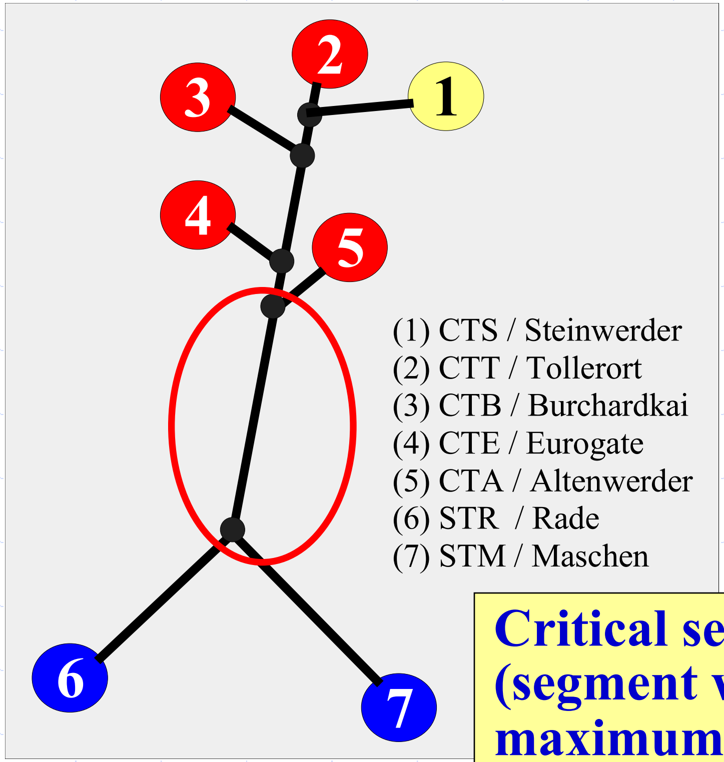
Shuttle connections for the seaport container terminals of Hamburg (2)

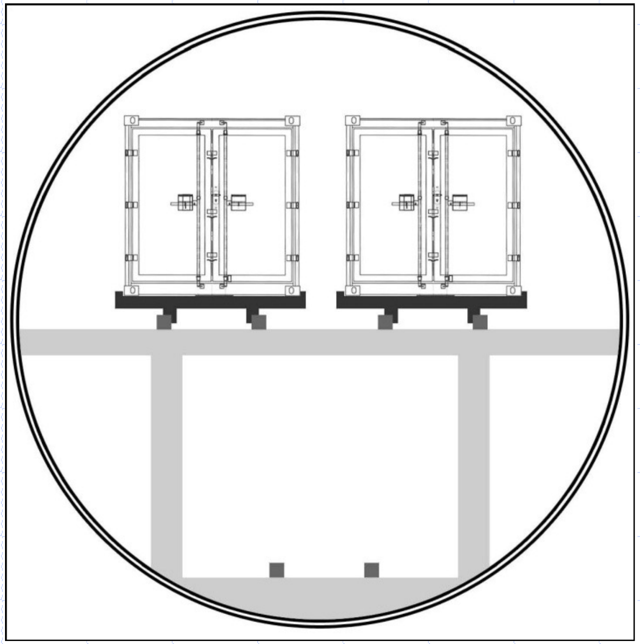


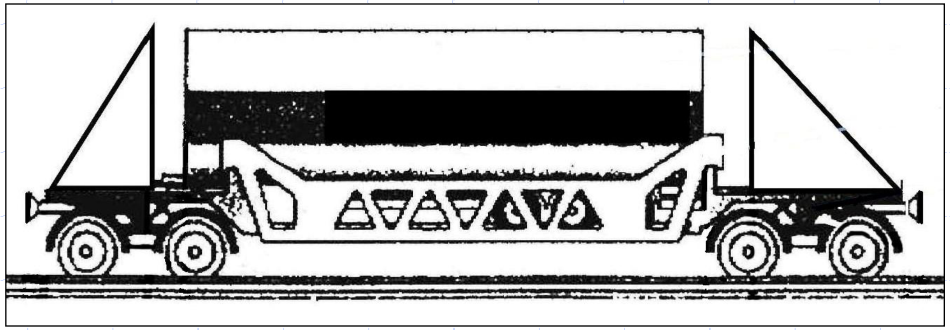


(1) CTS / Steinwerder
(2) CTT / Tollerort
(3) CTB / Burchardkai
(4) CTE / Eurogate
(5) CTA / Altenwerder
(6) STR / Rade
(7) STM / Maschen

Critical section (segment with maximum utilization)

Design of shuttle connections / Underground transport system (1)





C&U system Hamburg (Prefeasibility study)

Design of shuttle connections / Underground transport system (2)

Swiss Metro concept (Concept study)

Example of an automated container terminal (Container Terminal Altenwerder (CTA), Hamburg, Germany)

Historic Overview

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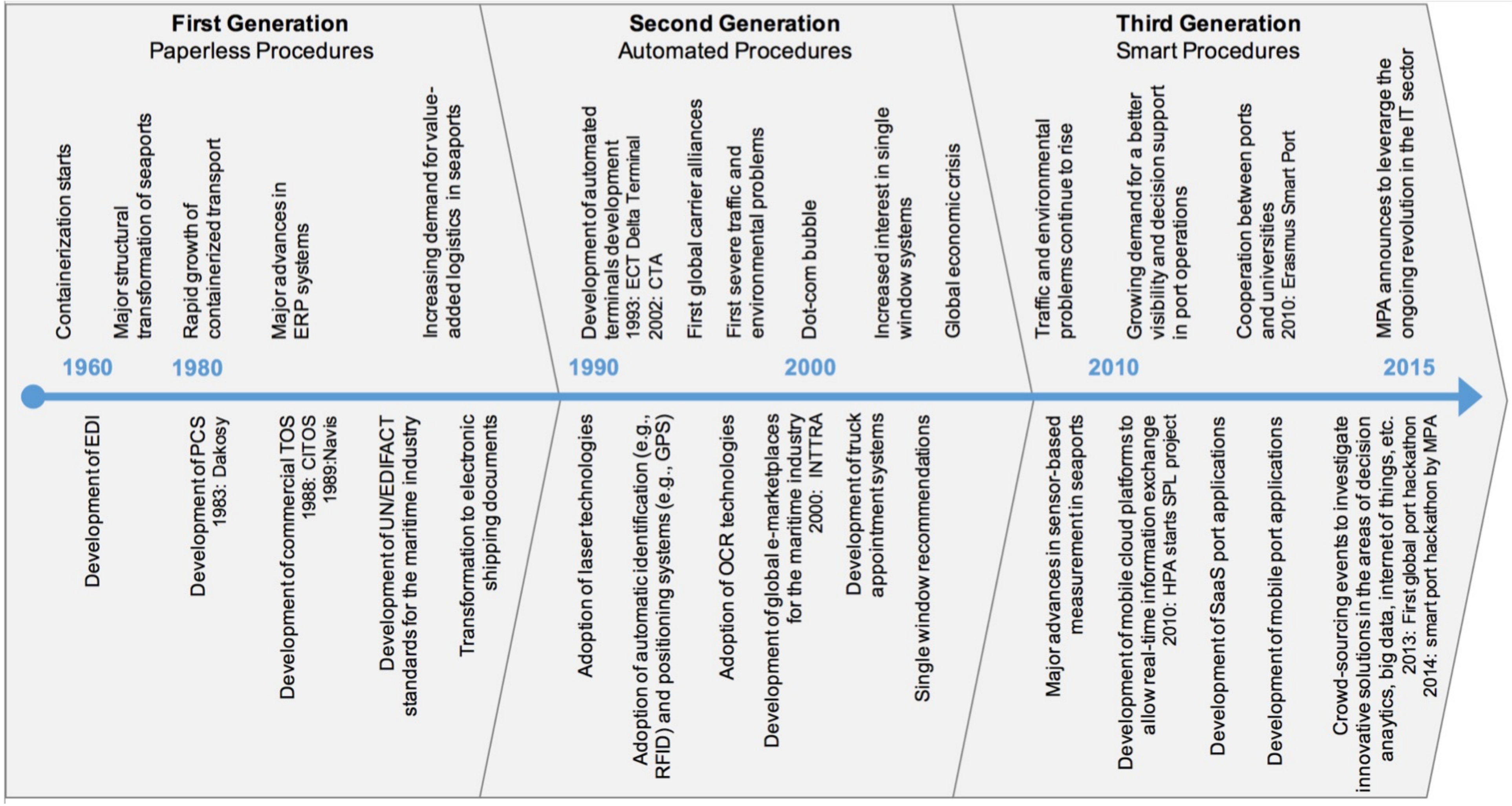


→ History of ports illustrates how digital innovation shapes processes and triggers modernization of ports

→ **2020-2025 and beyond: Digital Twin; Generative AI**

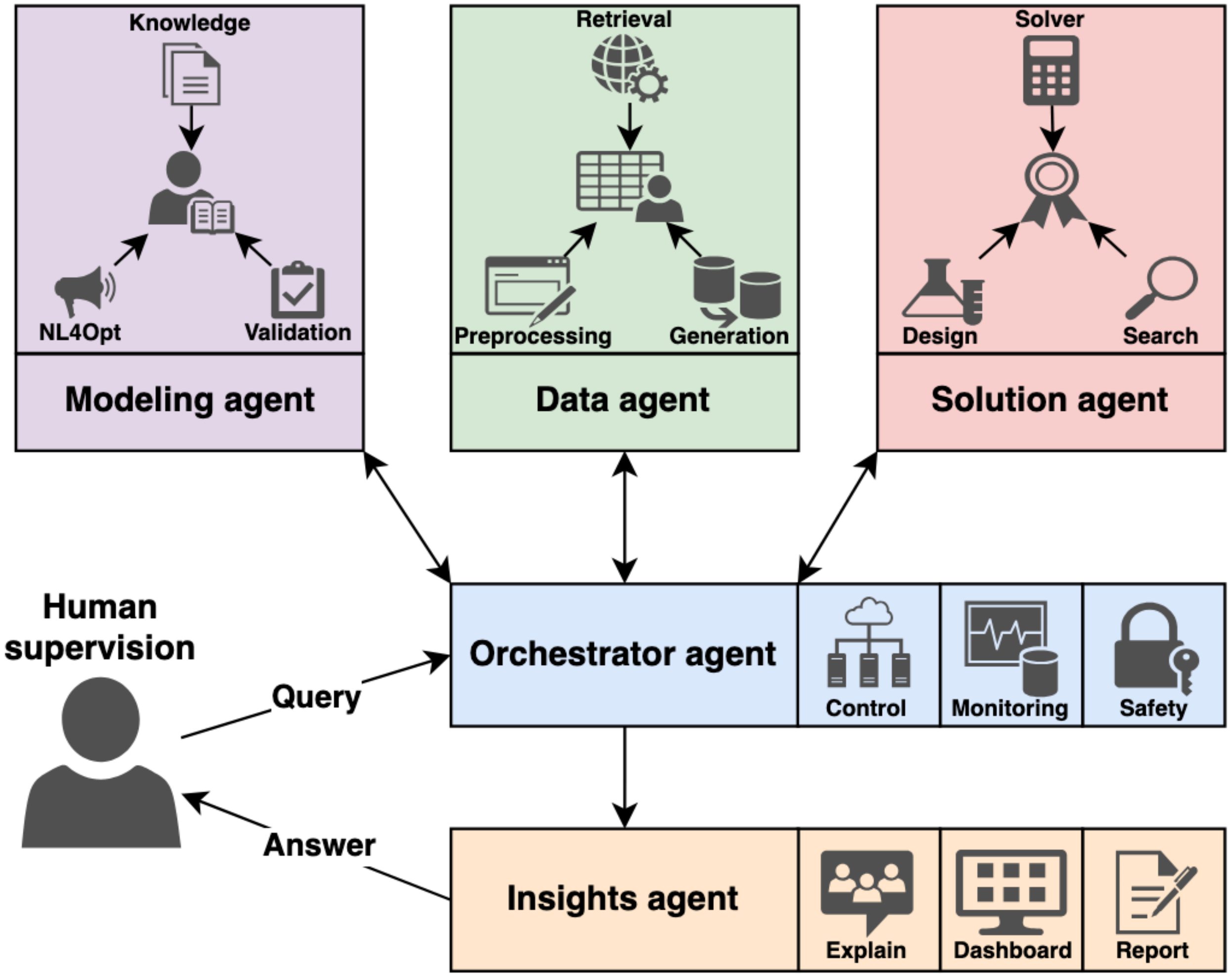
→ **2025-2030 and beyond: Agentic AI**
(related to Kondratieff Cycles)

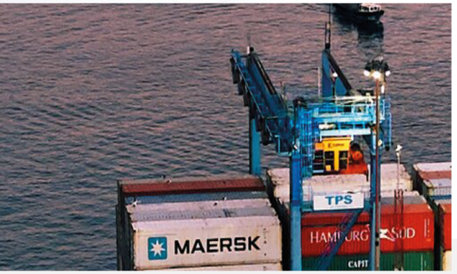
Generative and Agentic AI

- Large language models (LLMs) as backbone of todays human-computer interaction systems through various interfaces
- Early issues such as hallucinations can be mitigated with retrieval-augmented generation (RAG) approaches, particularly based on knowledge graphs [RAG operates by fetching relevant facts from external repositories and feeding them to the LLM to guide its output. The process is split into two primary pipelines: Data Injection and Query & Retrieval.]
- Shift from single agents to multi-agent systems (MAS) (not really a new concept), thus also agentic generative AI (emphasizing LLM-based agents)
- Considering technical, security, and transparency challenges, as well as the trade-off between augmentation, automation, and autonomization (human-in-the-loop vs. human-out-of-the-loop)

Agentic Generative AI Workflow

- Idea: Instead of performing all tasks separately, **combining** them into a workflow in a **MAS architecture**
- **Modeling, data, and solution agent**: Performing previously presented tasks
- **Orchestrator agent**: Control, coordination, monitoring, safety
- **Insights agent**: Explainability of processes, visualization of results in dashboards





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Also:

(Relatively) New Technologies …
… e.g., VR / AR
… Digital content watermarking (related to generative AI)

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Digital Twin - Strict Definition

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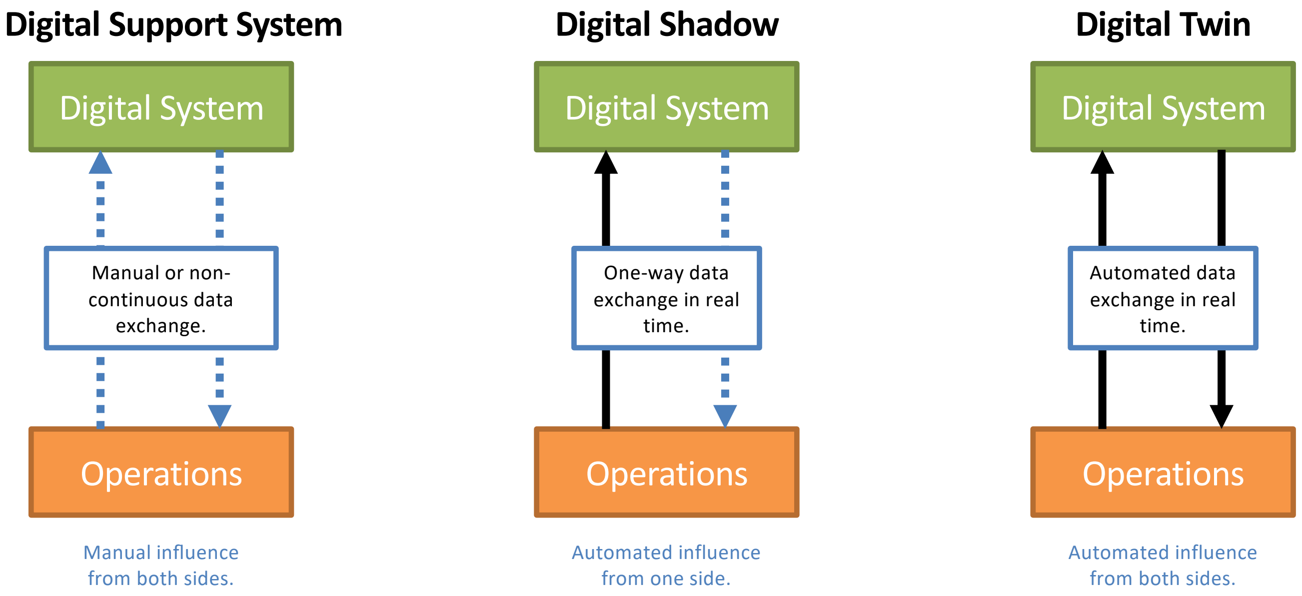
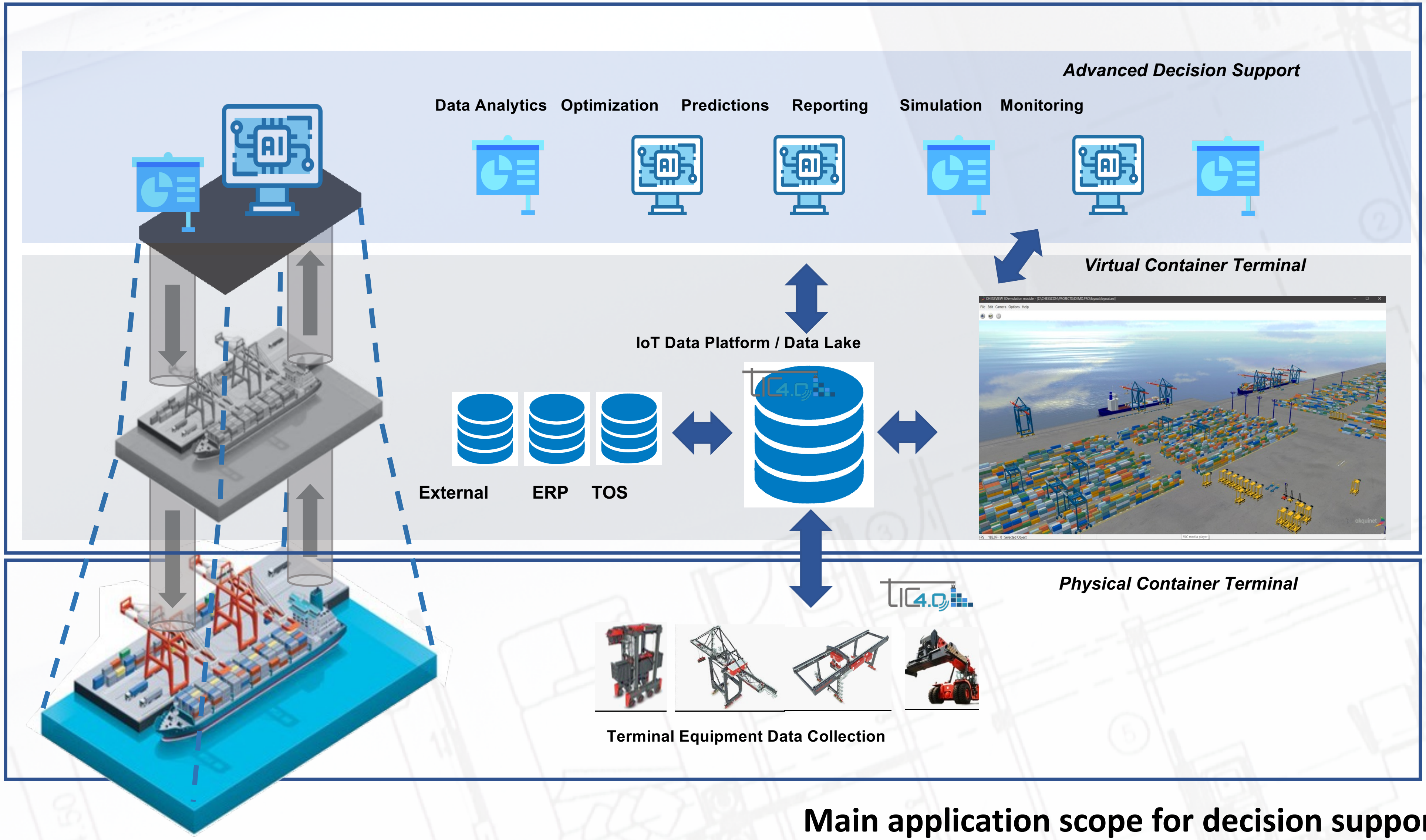
What is a digital twin?



Fuller, A., Fan, Z., Day, C., Barlow, C., 2020. Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access 8, 108952–108971.

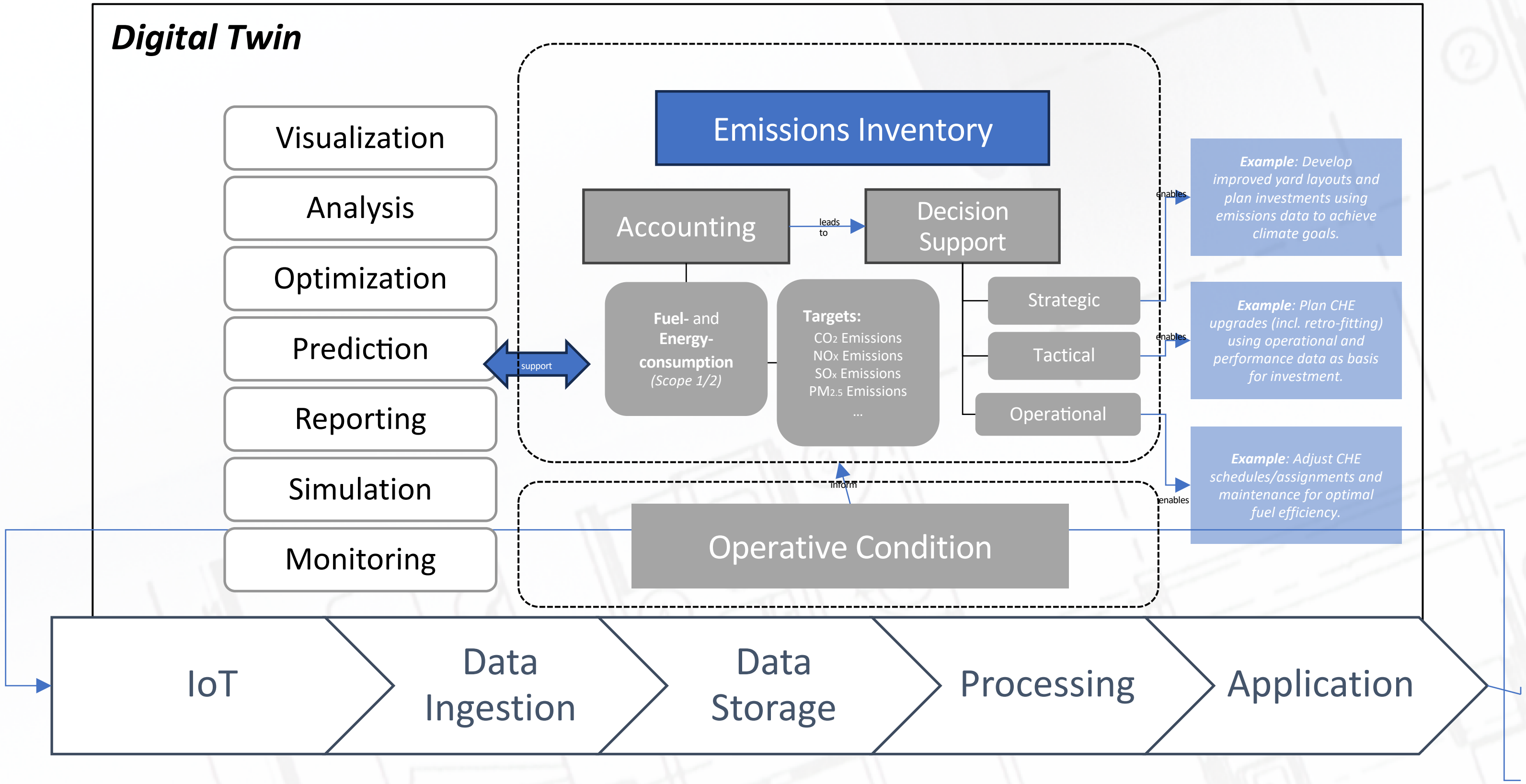


Digital Twins

Main application scope for decision support

- Transport Scheduling and Storage Assignment (with Straddle Carriers)
- Yard Housekeeping / Blocks Relocations Problem
- Integration of Transport Predictions for Import Containers
- Predictive Maintaince and Shift Planning

Framework / Digital Twin



Example Use Case: Slow Steaming

Sustainability / Environmental Management: Strategic Planning of Green Technologies

Shore side electricity (SSE)

Problems

- Large investment
- Uncertain environmental benefit
- Complex terminal operations

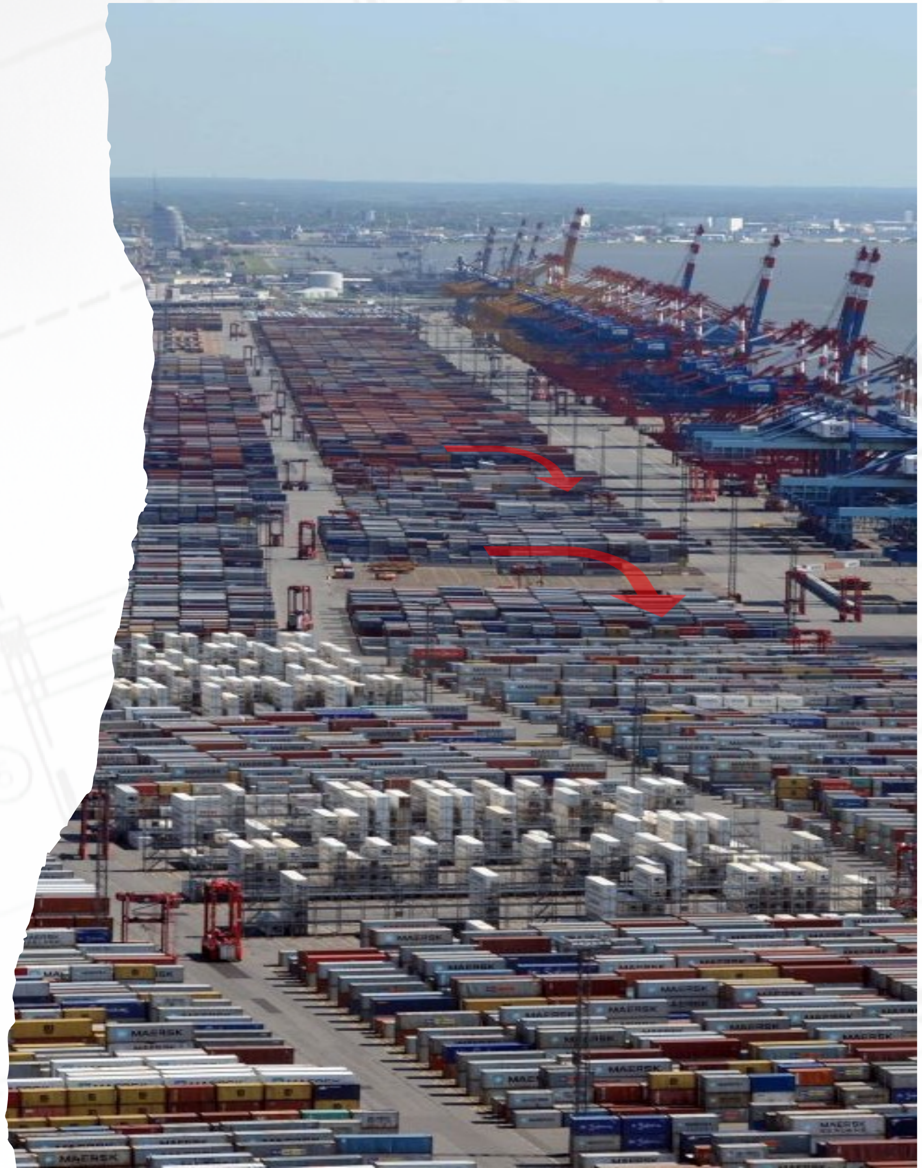
Combining Digital Twin and Sustainability

Turning the Terminal: Travel Times under the Influence of Weather at the Container Terminal

Target: Analyzing the driving times of straddle carriers in a container terminal if the container blocks are turned 90 degrees, thus changing weather influences on the drivers as well as potentially reducing weather counter measures.

Prerequisites:

- Prediction of drive times with artificial distance matrix.
  - Need for new/simulated distance matrix with turned blocks. Or focus just on an artificial terminal with driving models developed at EUROGATE.
- Analysis of straddle carrier drive times with weather influence.
  - Machine-learning-based drive-time paper as foundation.
  - Further feature engineering required (i.e., wind direction in relation to mean driving direction.



Port Call Learning and Optimization Challenges: The PortCall.Zero Project

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PortCall.Zero – Learning and Opt. Challenges

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Decarbonization strategies are typically distinguished as **efficiency improvement** and **technological switch approaches**. In this project, we can consider both types of strategies to decarbonize the port call process. In practical terms the **three main aims of the project** are consequently:

1. Port call optimization to **minimize waiting emissions** ("efficiency improvement").
2. Port call optimization for **port calls that are optimized for shore power and alternative fuel usage** ("technological switch").
3. Create a **virtual port call environment** for net zero port call scenario evaluation.

Port Authority: How will EU ETS effect our port calls? How to make our port call systems smarter? How can we improve inhouse ETA predictions?

City of Rotterdam: How do we reduce emissions in our area?

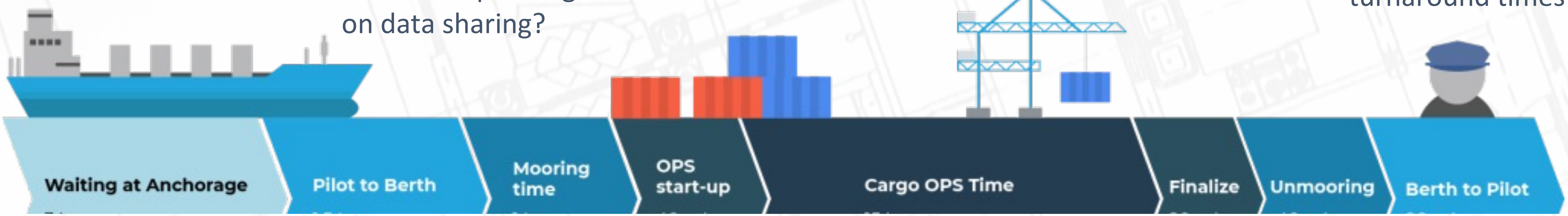
Maersk: We dream of virtual port call queue!

Kotug: How can we do anticipatory tugboat scheduling without depending on data sharing?

PortXChange: How do we know how much shore power will be needed?

APMT: How can we make shore power happen to reduce terminal scope 3 emissions? **Portwise** +1.

NextLogic: How can we improve ETA predictions to minimize barge turnaround times?



Environmental Impact - Highlights

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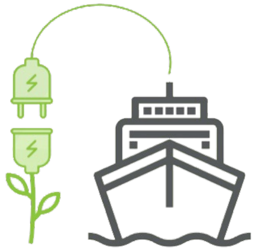
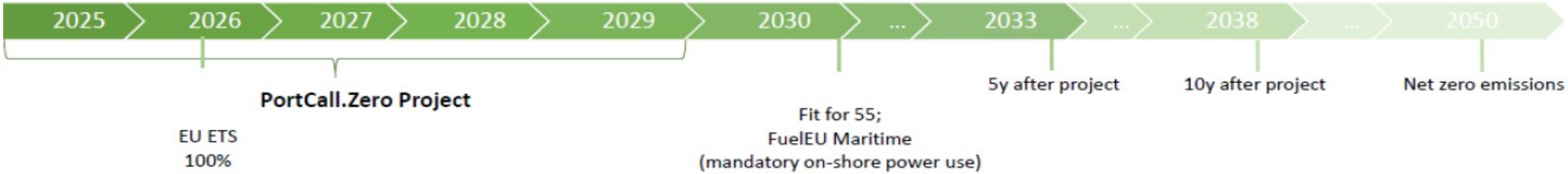
Innovative models for shore power and alternative fuel port calls

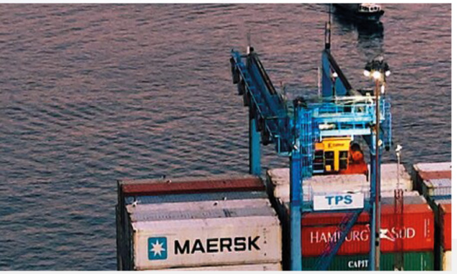
100% Shore Power Berths
in Rotterdam and Moerdijk

Just in time reduces up to 150M tons of emissions



Net zero emissions goal is reached in ports around Europe





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Interconnected maritime logistics ecosystem using real-time data, artificial intelligence, automation, clean energy, and collaborative governance to optimize cargo flows while improving safety, resilience, environmental performance, and social value.

Topics for now and the future:

- **Digital Transformation (incl. Agentic AI)**
- **Digital Twin**
- **Resilience (from operations to climate and beyond)**
- **Buffers**
- **Sustainability**
- **Governance**
- **Energy transition**
- **Measuring (e.g., vulnerability, emissions)**

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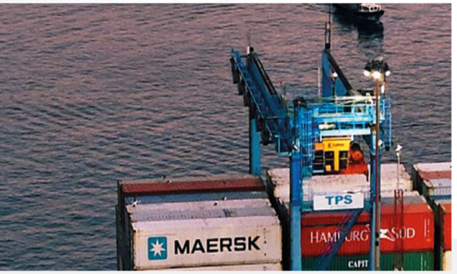

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Maritime Shipping in 2040

Gracias. Proguntas?

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