Advancing Inland Waterways with Digital Twins – Exploring CRISTAL project innovations and MultiRELOAD project demonstrator

Key takeaways

Digital twin, what does it mean concretely? David Cipres

Origin of Digital Twin Concept:

- The idea originated at NASA in the 1970s.
- NASA created physical replicas ("twins") of spacecraft to troubleshoot problems remotely.
- Today, digital replicas are built instead of physical ones due to technological advances.

What is a Digital Twin?

- A digital twin is a virtual replica of a physical object, system, or process.
- It mirrors the behavior and performance of the real-world counterpart.
- The model uses real-time data from sensors and other sources to simulate, analyze, and improve the real-world system.

Key Functions of a Digital Twin:

- Diagnostics: Analyze system behavior.
- Forecasting: Predict future states and issues.
- Visualization: Make complex systems easier to understand with virtual models.

Application Levels: Digital twins can be applied at various scales:

- **Component Level:** e.g., modeling the brakes of a car.
- **Asset Level:** e.g., modeling an entire engine.
- **System Level:** e.g., modeling a full vehicle.
- **Process Level:** e.g., modeling the entire manufacturing process or supply chain of a vehicle.

Importance in Logistics and Transportation:

- Especially useful for **complex systems like inland water navigation.**
- Help to optimize operations, find solutions virtually, and implement them in the physical world.

Digital twins are becoming essential tools for **problem-solving**, **innovation**, and **efficiency improvements** across industries, particularly logistics.

alice | Alliance for Logistics Innovation through Collaboration in Europe

MultiRELOAD PORT SOLUTIONS FOR SUSTAINABLE MOBILITY

CRISTAL

CRISTAL project: operational decision support with Digital Twins Introduction of the Synchromodal Corridor Management System (SCMS) integrated with Digital Twins to support operational decision-making in IWT.

Main Challenges Identified:

- **Aging infrastructure** and **extreme weather events** disrupt inland waterways.
- **Low water levels**, strongly tied to climate change, impact cargo transport capacity.

Project Goals (CRISTAL Project):

- Increase the **modal share** of inland waterway transport by 20%.
- Improve **reliability** of river corridors to at least 80%.
- Ensure **resilience** during extreme weather events (maintain 50% capacity).
- Develop **cross-border governance models** for cooperation among stakeholders.

Approach and Innovations:

- Use of **sensor technologies** (acoustic emissions, surface radar, fiber optics, smart buoys) to monitor river and infrastructure conditions.
- Creation of **Digital Twins** to:
    - Predict infrastructure and navigability issues.
    - Provide real-time insights to **Synchromodal Corridor Management System (SCMS)**.
- Digital twins feed data to infrastructure managers and support **operational and strategic planning**.

Digital Twin Applications:

- **Forecasting river navigability** up to two weeks ahead.
- **Early detection** of infrastructure problems.
- Enabling **predictive maintenance** and **proactive operations planning**.
- **Supporting CO_2 reduction efforts** by optimizing transportation choices.

SCMS Functionalities:

- **Early Detection and Info Service:** Adds predictive forecasting to existing real-time notices.
- **Disruption Impact Identification Service:** Assesses feasibility of transportation routes.
- **Action Toolbox:** Proposes multimodal alternatives if disruptions occur.
- **Corridor Observatory:** Provides KPIs and analytics for policy support.

Value Proposition Analysis:

- Main value identified: **Visibility and Single-Point Status View** of inland waterways.
- Additional value: **Supporting modal shift** by reducing uncertainties in the transport chain.
- Higher value created when waterway transport reliability is **low**, as the system mitigates risk.

Survey

MultiRELOAD project: Environmental Monitoring in Ports Demonstration of a Digital Twin platform applied in the Port of Duisburg for real-time environmental monitoring

MultiRELOAD Project Background:

- 24 partners across 8 European countries (including ports like Duisburg, Vienna, Basel).
- Two main corridors: Rhine-Alpine and the Danube Corridor.
- Project involves 7 demonstrators across different transport innovations.

Definition and Use of Digital Twins:

- Digital Twin = Virtual representation of a physical system, integrating sensor and operational data.
- Applications in ports: Improve efficiency, environmental monitoring, real-time analytics, and predictive decision-making.
- Two types of Digital Twins:
    - Descriptive: Real-time status visualization.
    - Operational: Predictive analytics and autonomous decision-making.

Multimodal Node Digital Twin Ambition:

- Develop a centralized platform to:
    - Aggregate data from sensors, port systems, external services.
    - Visualize port status in real-time and historically.
    - Apply big data analytics, simulations, and predictions for better decision support.

Platform Architecture and Capabilities:

- Built using open-source, big data, and AI technologies.
- Intelligent Services Layer allows adding customizable services like:
    - Smart lighting, traffic management, environmental monitoring, berth automation, and security features.

Demonstrated Functionalities (Live Demo):

- Real-time sensor monitoring: Weather, traffic, environmental quality.
- Notifications and alerts based on defined thresholds.
- Historical data analysis with different visualization types (heatmaps, time series).
- Satellite image integration: Monitor air and water quality via Copernicus datasets.
- Emission calculation for vessels during different navigation phases with visualization of emissions maps.

Transition to Operational Digital Twin:

- Demonstrated ability to act on infrastructure (e.g., control smart lighting, barriers) based on real-time data inputs.

Commercial Perspective:

- While the tool is developed within MultiRELOAD, it is also being positioned as a commercial solution for wider adoption beyond the project.

SLIDO SESSION – Main outcomes

What do you see as the biggest challenge for Inland Waterway Transport in adopting Digital Twins?

- Lack of digital infrastructure & data sharing (70%)

What is the most valuable insight DT can provide for IWT operations?

2 main priorities were raised:

- Real-time water level & navigability forecasts (2.76)
- Improved multimodal synchronization (2.72)

Would your organization invest in a DT in IWT and why?

Many participants expressed support for investing in digital twins in IWT, citing key benefits such as:

- Optimization of operations (mentioned multiple times).
- Increased transparency in transport systems.
- Monitoring infrastructure and providing real-time insights.
- Improved navigability and supply chain resilience.
- Use in multimodal transport integration, combining road, rail, and water

Some responses reflected uncertainty or conditional interest

What incentive would encourage wider adoption of Digital Twins in IWT?

- ***Financial Support***: Funding for infrastructure, sensors, and innovation projects is crucial.
- ***Data Sharing and Standards***: Greater emphasis on open data platforms, stakeholder education, and standardization across modes.
- ***Operational Efficiency***: Benefits like reduced waiting times, real-time usability, and improved ETA precision are key drivers.
- ***Environmental Pressures***: Climate change mitigation through better contingency planning and emission reductions encourages adoption.

- ***Collaboration Models***: Success depends on cooperation across transport modes and public-private partnerships.
- ***Market-Driven Perspective***: Some believe adoption should be led by market forces rather than subsidies.

When do you expect DT in use for IWT?

48% of participants envision a wider use of DT within 3 years and 38% within 5 years.

Within CRISTAL and MultiRELOAD projects, what are the main challenges?

Primary Challenges Identified:

Data Quality and Quantity:

- A critical issue for both projects; machine learning models (e.g., predicting water levels) require large volumes of accurate and diverse historical and real-time data.

Interoperability:

- There is a lack of standardized frameworks, which hinders seamless integration of digital twins with various systems and platforms.

Big Data Management:

- Managing, storing, and processing the large volumes of data generated by IoT devices (like sensors and cranes) is a major concern.

Real-Time Computing:

- The goal is to have digital twins that reflect real-world changes instantaneously to support informed decision-making.

Scalability:

- Solutions developed during the project must be scalable and usable beyond the project lifecycle.

Developer Perspective Summary:

- Data is central to all challenges and opportunities: quality, quantity, standardization, management, and real-time use.

Next Steps Highlighted:

- Need to hear from ports, terminals, and end users who will share their perspectives on the practical challenges and expectations for digital twins.

Panel Discussion: Challenges and Opportunities

- **Moderator**: Tomasz Dowgielewicz
- **Panelists**:
    - Jan-Christoph Maass (Duisport)

- Peter Rojko (Hafen Wien)
- Salvador Furio (Fundación Valenciaport)
- David Cipres (ITA)
- José Antonio Clemente Pérez (Prodevelop)
- Orestis Tsolakis (CERTH)

Key Discussions:

Examples of Digitalization in Other Modes:

Ports (Vienna, Valencia, Duisburg):

- Use of AI for operational optimization (e.g., container stacking, damage detection).
- Rail gates, road gates, and river gates installed for monitoring movements across different transport modes.
- Real-time monitoring, OCR detection, and predictive maintenance of port infrastructure

Rail Sector:

- Implementation of Port Community Systems (PCS) for rail logistics.
- Projects like ALO implementing TAF-TSI standards to improve train operations.

Air Sector:

- Mention of the Single European Sky initiative as an example of digitalization to improve real-time information exchange and operational efficiency.

How Digital Twins Boost Multimodal Logistics:

- Enhancing real-time coordination across transport modes.
- Predictive maintenance and emissions monitoring are becoming key for sustainable operations.
- Emphasis on the need for interoperability between different digital twin systems to enable seamless supply chain integration.
- Data (historical and real-time) is crucial for predictive analytics and decision-making.

Commercialization of Digital Twin Solutions:

- Target customers: Ports, infrastructure managers, barge operators, logistics service providers.
- Solutions need to be modular and flexible, addressing different stakeholder needs (operational efficiency, infrastructure management, emissions tracking).
- Business models discussed: Outright sale, licensing, service-based models.

- Acknowledgment that commercialization maturity varies – more advanced for operational systems like SCMS (Synchromodal Corridor Management System) than for standalone digital twins.

Challenges and Future Outlook:

- Lack of standardized data exchange protocols between different nodes and transport modes.
- A call for initiatives like the Physical Internet vision to connect optimized nodes (ports, terminals) across the supply web.
- Compilation of examples into a white paper to serve as a reference for wider adoption.

Digital Twins and Climate Resilience:

- Digital twins can help predict and mitigate climate-related risks (low water, floods, droughts) by enhancing the predictability of inland waterways.
- Importance of leveraging big data and AI to build resilience against disruptions.
- Ports need to use historical and real-time data effectively for better forecasts and operational planning.

Final Reflections:

- Digital twins are powerful but must be linked with real-time data ingestion and standardized protocols for true system-wide optimization.
- Participants were encouraged to continue contributing use cases and examples to ongoing collaborative research efforts.