Digital Traffic Management as Foundation for Sustainable Development of Small and Medium Ports

Contribution to the Call for Evidence of the EU Ports Strategy

Characteristics of document

Title	Digital Traffic Management as Foundation for Sustainable Development of Small and Medium Ports
Reference	Contribution to the Call for Evidence of the EU Ports Strategy
Institute	DLR – Institute of Transportation Systems
Created by	Dr. Peter A. Meincke
Persons involved	Thomas Christ, Andrei Popa
Checked by	Florian Brinkmann
Approval by	Christian Meirich, Florian Brinkmann
Date	21.07.2025
Version	END-version
File path	C:\Users\meincke\Documents\+DLR15.09.2025\+++ECTRI EU Hafen\2025.07.20 EU-Digital Traffic Management as Foundation for Sustainable Development of Small and Medium Ports_P.A.Meincke DLR 20.07.2025 Endversion.docx

Contents

Digital Traffic Management as Foundation for Sustainable Development of Small and Medium Ports

1. Introduction

The present elaboration "Digital Traffic Management as a Foundation for Sustainable Development of Small and Medium-Sized Ports" shall be submitted to the ECTRI Thematic Group Freight and Logistics as a scientific contribution to the Call for Evidence of the EU Ports Strategy. Given the strategic importance of small and medium-sized ports for European transport infrastructure and the multifaceted challenges of the green and digital transformation, this research work represents an evidence-based contribution to scientific policy advice.

Small and medium-sized ports (SMPs) function as critical multimodal nodes in European supply chains, connecting maritime, inland waterway, road, and rail networks, yet face particular challenges in implementing sustainable and digital solutions. While larger ports possess substantial financial resources and organizational capacities, SMPs frequently suffer from resource constraints and risk aversion that limit their ability to implement sustainability measures. Digital transformation, however, offers considerable potential to overcome these barriers through intelligent traffic management systems that can improve both operational efficiency and environmental performance across all transport modes.

The ECTRI Thematic Group Freight and Logistics with rapporteurs from KTI, CERTH/HIT and VTI contributes its long-standing expertise in the areas of resilience and digitalization of intermodal transport chains, door-to-door freight transport, urban logistics and decarbonization. This competence is underpinned by DLR's FuturePorts project, which develops innovative technologies for the ports of the future, including automated traffic management systems and digital twins for optimizing freight transport with particular focus on rail-port integration.

The EU Ports Strategy recognizes ports as strategic enablers of the green transition, digital transformation and supply chain resilience. The EU's modal shift objectives, reinforced by the Fit for 55 package, emphasize the critical need to double rail freight traffic by 2050, making efficient rail-port connectivity essential for achieving climate neutrality goals. At the same time, it emphasizes the urgent need to support smaller ports in digital transformation and to develop industry-wide digitalization standards. This elaboration addresses these challenges through a systematic analysis of the potential of digital traffic management systems as a catalyst for sustainable development in SMPs and provides concrete recommendations for the strategic orientation of EU port policy in the context of the Twin Transition.

2. Executive Summary

Digital traffic management represents the indispensable first step toward automation for small and medium-sized ports (SMPs) while simultaneously enabling immediate improvements in efficiency, sustainability, and economic viability. Critically, true transformation demands digitalization not only for truck (road) traffic but also for rail-based container flows and hinterland connections. Through intelligent sensor and control systems with 24/7 monitoring capabilities, multimodal cargo handling can be accelerated, environmental impact reduced, and the competitiveness of these critical logistics nodes secured. The concept integrates proven technologies such as IoT sensor networks, AI-powered multimodal coordination applications, and AnyLogic simulation software into a coherent system that serves as the technological foundation for future automation steps across all transport modes.

3. Strategic Context and Challenges

3.1. EU Port Strategy and Digitalization Imperatives

The European Commission launched two strategic consultations in 2025 that will shape the future of ports and maritime industry. The EU Port Strategy emphasizes competitiveness, security, energy transition, and sustainability as core priorities. The strategy explicitly recognizes that achieving modal shift objectives requires seamless multimodal integration, particularly between maritime and rail transport. For small and medium-sized ports, which constitute the majority of European port facilities, digital transformation presents both significant opportunities and specific challenges.

The EU's twin transition toward sustainability and digitalization, reinforced by the European Green Deal and Fit for 55 packages, creates concrete obligations for ports to reduce emissions, implement alternative fuel infrastructure, and enhance operational efficiency. The EU's target to double rail freight traffic by 2050 directly impacts port operations, as approximately 60% of European port hinterland traffic could potentially shift to rail with proper digital integration. However, SMPs often lack the financial resources and technical expertise available to major container terminals, necessitating cost-effective, scalable solutions that deliver immediate operational benefits while preparing for future automation.

3.2. Current Challenges in Small and Medium Ports

Research indicates that SMPs face multiple operational inefficiencies that digital traffic management can address:

- Traffic congestion and bottlenecks during peak loading/unloading periods
- Lack of real-time visibility into cargo handling progress and multimodal vehicle movements
- Suboptimal coordination between arriving trucks, trains, ships, and port operations
- Inefficient intermodal transfer processes between rail, road, and maritime transport
- Manual planning and siloed IT systems that impede efficient handling of intermodal container trains
- Inefficient resource utilization of berths, cranes, rail sidings, and storage areas
- Environmental impacts from unnecessary vehicle idling and extended waiting times

These challenges result in increased operational costs, reduced competitiveness, and preventable emissions that conflict with EU sustainability objectives. Particular challenges exist in rail-port integration, where the lack of digital coordination between rail operators, terminals, and port authorities leads to suboptimal train scheduling and container handling.

4. Digital Traffic Management Concept

4.1. Core Infrastructure Requirements

The proposed digital traffic management system builds on sensor-based infrastructure integrated throughout the port area to enable continuous monitoring of multimodal traffic flows and cargo handling processes. Key components include:

IoT Sensor Networks: Deployment of smart sensors throughout port infrastructure to monitor truck and train vehicle movements, berth occupancy, rail siding utilization, crane operations, and cargo loading progress. Additional sensors monitor rail track conditions, train positioning, and intermodal container transfer points. These sensors provide real-time data streams that feed into a central traffic management system.

Intelligent Multimodal Control Center: A centralized system that processes sensor data alongside logistical information from incoming trucks, trains, and vessels, generating optimized routing instructions and operational coordination. The system integrates with rail infrastructure managers, railway undertakings, and terminal operating systems to enable seamless coordination of intermodal operations. This system serves as the digital backbone for traffic optimization and future automation integration.

4.2. AI-Powered Driver Application

Since fully automated truck and train operations remain technically unfeasible for most SMPs, the initial implementation focuses on a specialized multimodal coordination application that leverages artificial intelligence to generate optimized routing and provide real-time navigation assistance for both road and rail transport.

The application would provide:

- Real-time traffic optimization based on current port conditions for trucks and trains
- Integrated slot booking for both road vehicles and rail services
- Arrival time coordination across all transport modes
- Turn-by-turn navigation within complex port layouts including rail marshalling areas
- Digital interfaces for locomotive crews and train dispatchers
- Real-time coordination between container ship schedules, rail timetables, and truck arrivals
- Two-factor authentication for enhanced security compliance
- Feedback loops that continuously improve routing algorithms through multimodal movement data collection

This approach aligns with successful implementations like **Hamburg's railMybox platform**, which enables digital booking of intermodal container transport with the same simplicity as airline reservations. This approach has demonstrated success in major European ports, with over 200,000 trucks now handled through digital applications in Hamburg's terminals, and similar systems being developed for rail freight coordination through initiatives like Rail Connected in Rotterdam.

4.3. Integration with Existing Infrastructure

A critical advantage of this approach is its ability to leverage and upgrade existing security infrastructure. Many SMPs already have surveillance cameras for security purposes; these systems can be enhanced with traffic management capabilities through software upgrades and additional sensors. Similarly, existing rail signaling and yard management systems can be upgraded with intelligent digital interfaces that communicate with port traffic management systems. Conversely, ports installing traffic monitoring systems can integrate security functions, maximizing infrastructure investment efficiency.

5. 24/7 Surveillance and Security Integration

5.1. Comprehensive Monitoring Capabilities

The digital traffic management system incorporates 24/7 camera surveillance with infrared sensor technology to ensure round-the-clock security and operational monitoring. This dual-purpose infrastructure addresses both security requirements and traffic optimization needs:

Day/Night Operations: Advanced camera systems with infrared capabilities enable continuous monitoring regardless of lighting conditions. This ensures consistent traffic management and security coverage during all operational hours across road, rail, and maritime interfaces.

Integrated Analytics: AI-powered video analytics can simultaneously detect security threats, identify traffic bottlenecks, monitor rail and intermodal equipment performance, and track cargo handling progress. Modern rail OCR systems, such as those developed by ABB and Camco Technologies, can automatically identify and track containerized cargo moving via rail, providing real-time inventory of complete freight trains. This multi-functional approach maximizes the value of infrastructure investments.

Rail Infrastructure Monitoring: Camera surveillance and access control extended to on-port rail infrastructure, including rail tracks, sidings, and intermodal exchange points, with unified data streams from all transport modes.

Real-Time Response: Centralized monitoring enables immediate response to both security incidents and operational disruptions, minimizing their impact on port efficiency.

5.2. Cybersecurity for Critical Infrastructure

As digitalization increases, ports are becoming prime targets for cyber threats. The US Coast Guard introduced new cybersecurity regulations for ports in 2025, effective July 2025, highlighting the growing importance of this issue. The digital traffic management system must therefore integrate robust cybersecurity measures:

- Network segmentation between operational technologies and IT systems, including rail control systems
- Regular security assessments and penetration testing
- Encryption of all data transmissions between sensors and central systems
- Access control with multi-factor authentication for critical systems

6. Simulation and Forecasting with AnyLogic

6.1. AnyLogic-Based Traffic Simulation

The digital traffic management system incorporates AnyLogic simulation software to model various operational scenarios and optimize traffic control mechanisms. This simulation capability provides:

Integrated Scenario Analysis: Testing different multimodal traffic management strategies, infrastructure modifications, and operational procedures in a risk-free virtual environment. Ports can simulate varying shares of rail and road transport to test modal shift effects and optimize intermodal coordination. Ports can evaluate the impacts of changes before implementation, reducing risks and optimizing investments.

Multimodal Predictive Capabilities: Using historical data and real-time conditions to forecast truck and train traffic patterns, identify potential bottlenecks, and proactively adjust operations. AI-driven forecasting of required train paths and shunting operations based on vessel arrivals and hinterland demand. This enables preventive rather than reactive management.

Continuous Optimization: Feedback from actual operations continuously improves simulation accuracy and traffic management algorithms. The system integrates operational data from both rail and truck movements for optimized synchronization of transport modes. The system learns from real-world performance to enhance future predictions and recommendations.

Capacity Planning: Long-term analysis of port capacity requirements and infrastructure development needs based on traffic growth projections and operational efficiency improvements with specific focus on rail capacity utilization and modal shift potential.

6.2. Real-World Success Examples

Research has demonstrated that AnyLogic simulation in port environments can identify potential capacity increases of 20% through operational changes alone, while also revealing critical infrastructure bottlenecks that limit future growth.

The Port of Le Havre successfully used AnyLogic to optimize its multimodal terminal, comparing different automation scenarios and identifying optimal configurations for cost, service quality, and network structure improvements. NSW Ports in Australia used AnyLogic modeling to develop a comprehensive rail strategy, optimizing rail operations and maximizing rail capacity through improved scheduling and infrastructure utilization.

7. Implementation Pathway and Technology Partnerships

7.1. Phased Rollout Strategy

The digital traffic management system should be implemented through a structured, phase-based approach that allows SMPs to realize immediate benefits while building toward comprehensive automation:

Phase 1: Basic Traffic Monitoring

- Install core sensor infrastructure and camera systems for road and rail
- Implement multimodal coordination application with basic routing for trucks and trains
- Establish digital interfaces with rail infrastructure managers and railway operators
- Establish central monitoring capabilities

Phase 2: Advanced Optimization

- Deploy AI-powered traffic management algorithms for coordinated road-rail operations
- Integrate rail slot management and intermodal container tracking systems
- Integrate simulation and forecasting capabilities for multimodal scenarios
- Enhance security and operational analytics

Phase 3: Automation Preparation

- Upgrade infrastructure for future automated vehicle compatibility including rail automation systems
- Integration with Digital Automatic Coupling (DAC) systems as they become available
- Implement advanced communication protocols
- Develop interfaces for autonomous rail and road system integration
- Develop interfaces for autonomous system integration

7.2. Strategic Technology Partnerships

Successful implementation requires collaboration with specialized technology providers who can supply necessary infrastructure, sensors, and software systems for port environments. Recommended partnership areas include:

Traffic Technology Companies: Providers of sensor networks, IoT devices, and traffic management software specialized for port environments, such as COCUS with 5G campus network expertise.
Rail Technology Specialists: Partners specializing in rail digitalization, including companies like Zedas (slot and shunting management), Rail-Flow (intermodal digital hub), and ICT Group (intermodal transport management systems).
Intermodal Logistics Service Providers: Partners who can ensure practical relevance and real-world applicability of proposed solutions across all transport modes.
Simulation Software Specialists: AnyLogic implementation partners with port-specific expertise and proven track records in maritime and rail logistics optimization.

7.3. 5G Campus Networks as Enablers

The PORTABLE 5.0 project successfully demonstrates implementation of 5G campus networks in small and medium German ports like Wismar, Stralsund, and Karlsruhe. This private 5G infrastructure provides:

- Low latency for real-time applications including rail control systems
- High bandwidth for extensive sensor data transmission from multimodal sources
- Network security through private, dedicated connections
- Scalability for future automation requirements across all transport modes

8. Expected Benefits and Outcomes

8.1. Operational Efficiency Gains

Implementation of digital traffic management systems delivers multiple quantifiable benefits for SMPs:

Reduced Waiting Times: Optimized routing and real-time coordination can reduce truck and train waiting times by 15-25%, directly improving operational efficiency. Improved synchronization between train arrivals, ship loading schedules, and truck dispatch reduces overall dwell times.

Enhanced Throughput: Better multimodal traffic flow management enables ports to handle increased cargo volumes without proportional infrastructure expansion. Modal shift enablement through improved rail capacity utilization supports EU goals of shifting more containers to environmentally favorable transport modes.

Resource Optimization: Improved coordination between trucks, trains, cranes, and berths maximizes utilization of existing infrastructure. Synchronized train arrival/departure with ship loading and truck handling operations.

8.2. Environmental and Sustainability Impact

Digital traffic management directly supports EU environmental objectives through:

Emissions Reduction: Decreased vehicle idling time and optimized routing reduce CO_2 emissions and air pollution in port areas. Each container moved from road to rail reduces CO_2 emissions significantly - trains can transport the equivalent of 50 trucks while consuming only a fraction of the required fuel.

Modal Shift Achievement: Digital coordination systems enable SMPs to participate fully in intermodal and synchromodal transport chains, supporting the EU's goal to double rail freight traffic by 2050.

Energy Efficiency: Integration with renewable energy systems and smart grid technologies enhances overall port sustainability.

Green Deal Alignment: Supports EU goals for carbon-neutral ports by 2050 through improved operational efficiency and reduced environmental impact.

8.3. Economic Benefits

The proposed system delivers measurable economic advantages:

Cost Reduction: Terminal automation studies indicate potential labor cost reductions of up to 45% in fully automated systems, with proportional benefits available through partial digitalization. Rail freight digitalization, including Digital Automatic Coupling (DAC), can reduce operational costs and enable longer, heavier trains at higher speeds.

Infrastructure Efficiency: Dual-purpose security/traffic management systems maximize return on infrastructure investments across all transport modes.

Future-Proofing: Establishing digital infrastructure now prepares SMPs for future automation opportunities and regulatory requirements including integration with emerging rail technologies like DAC and autonomous train systems.

9. International Best Practices and Success Stories

9.1. Leading Smart Port Implementations

Port of Singapore: As one of the most technologically advanced ports globally, Singapore uses IoT sensors and AI to detect shipping anomalies such as piracy and reduce such attempts on cargo. Automated guided vehicles (AGVs) transport containers seamlessly, reducing dependence on manual labor while increasing operational speed.

Port of Hamburg: With 95% digitalization, Hamburg leads in networking and automation of logistics processes, including comprehensive rail integration. The Container Terminal Altenwerder features the largest container rail terminal in Europe with nine tracks of 720 meters each, handling approximately 900,000 TEU annually through automated OCR systems and integrated rail-road coordination.

Port of Los Angeles: The busiest port in the United States implemented sophisticated digital infrastructure with IoT and big data analytics to monitor cargo movements, optimize vessel traffic, and streamline terminal operations. The port blocks approximately 63 million cyber intrusion attempts per month, demonstrating the importance of robust cybersecurity.

East-West Gate Intermodal Terminal (Hungary): The world's first smart 5G railyard utilizing remote-controlled overhead cranes and advanced AI algorithms, demonstrating the potential for fully digitalized intermodal operations with capacity to handle 1.2 million TEU per year.

9.2. European Digitalization Initiatives

Rail-Connected Programme (Rotterdam): The Port of Rotterdam's Rail Connected initiative demonstrates successful digitalization of rail-port coordination, focusing on streamlined information exchange between carriers, rail operators and terminals, reducing manual operations and improving efficiency through digital pre-notification and cargo scheduling systems.

The **PortForward project** led by Fraunhofer IFF develops with 13 partners from six countries new concepts for making small and medium ports more intelligent, connected, and environmentally friendly. The project with five million euros EU funding until 2021 aims for a modular platform providing innovative technologies and services for networking and digitalization of infrastructures.

TRANS4M-R Flagship Project: Europe's Rail FP5-TRANS4M-R, worth EUR 95.1 million with 71 partners, focuses on establishing rail freight as backbone of lowest emission logistics chains through Digital Automatic Coupling (DAC) and fully digital freight train operations.

The **I²PANEMA project** (Intelligent IoT-based Port Artefacts Communication, Administration & Maintenance) digitalizes port processes through new IT strategies like Internet of Things. Developed demonstrators show how IoT concepts can be transferred to local processes, including truck and train tracking to optimize traffic, parking, and gate situations.

10. Financing and Funding

10.1. EU Funding Programs

The **"Digital Test Fields in Ports"** funding guideline from the Federal Ministry of Transport supports German sea and inland ports in digitalization with up to 80% funding share. The program recognizes that digital technologies can significantly improve the efficiency and quality of logistics processes.

Horizon Europe and other EU research framework programs offer substantial funding for port digitalization projects. The **PortForward** project received five million euros, while PORTABLE 5.0 is funded with 4.5 million euros. The **TRANS4M-R rail digitalization project** received 95.1 million euros, demonstrating significant EU commitment to rail-port integration.

10.2. Green Deal Financing

The **European Green Deal** and **REPowerEU** offer specific funding opportunities for sustainable port projects. Digital traffic management systems qualify through their emissions reduction and energy efficiency benefits for these programs. Projects focusing on modal shift and rail integration receive particular priority under Green Deal funding criteria.

Connecting Europe Facility (CEF) and **Cohesion Fund support infrastructure projects** that contribute to European connectivity and regional development. CEF specifically supports intermodal projects that enhance rail-port connectivity and contribute to TEN-T network objectives.

11. Policy Recommendations for EU Port Strategy

11.1. Strategic Policy Measures

Based on this analysis, we recommend that the EU Port Strategy specifically address the needs of small and medium-sized ports through:

Targeted Funding Programs: Dedicated financial support for SMP digitalization initiatives, recognizing their unique constraints and strategic importance. Funding programs should explicitly prioritize intermodal integration projects that connect rail and road systems.

Technology Transfer Support: Facilitate knowledge sharing and best practice dissemination between advanced and developing ports.

Multimodal Standardization Initiatives: Develop common technical standards for intermodal digital interfaces that enable seamless data exchange between road, rail, and maritime systems. Develop common technical standards that enable interoperability and reduce implementation costs.

Intermodal Pilot Project Programs: Support demonstration projects that validate digital traffic management approaches in diverse port environments with mandatory inclusion of rail connectivity components.

Training and Skills Development: Address the digital skills gap through targeted education and training programs for SMP personnel including multimodal coordination competencies.

11.2. Technical Standards and Interoperability

Maritime Connectivity Platform (MCP): Integration of multimodal traffic management systems into MCP to ensure seamless data exchange between ports, rail operators, and maritime stakeholders.

TAF TSI Integration: Utilization of Technical Specification for Interoperability relating to telematics applications for freight (TAF TSI) to integrate ports and terminals into digital messaging exchanges between railway undertakings and infrastructure managers.

Common Information Sharing Environment (CISE): Utilization of CISE framework for secure, standardized data transmission between port authorities and EU agencies.

NIST Cybersecurity Framework: Implementation of NIST CSF 2.0 and SP 800-82r3 as prescriptive roadmap for securing digital port infrastructures.

12. Economic Impact and ROI Analysis

12.1. Investment Costs and Payback

Typical implementation costs for digital traffic management systems in SMPs vary significantly depending on port size and existing infrastructure:

Phase 1: Basic Digitalization: (Estimated cost: € 0.8 – 1.5 million per port)

Includes:

- Base-level IoT sensor network
- Camera surveillance with infrared
- Central monitoring/control room
- Basic driver application
- Foundational cybersecurity

Justification:

- PortForward average: €1.0 million/port
- PORTABLE 5.0 experience: €1.5 million/port
- IoT hardware: €27,000–€45,000/port
- All core elements included

Phase 2: Advanced Integration (Estimated cost: €1.5 – 3.0 million per port)

Includes:

- AI-powered traffic optimization
- AnyLogic simulation & forecasting
- Multimodal (truck/rail/ship) coordination
- Advanced cybersecurity (NIST CSF 2.0)
- Rail–road interface systems

Justification:

- Adds AI, simulation (€180,000 max; tech-industry estimates)
- Adds NIST CSF implementation (€500,000 average)
- Integrates advanced systems based on modular extention from Phase 1

Phase 3: Automation Readiness (Estimated cost: €3.0 – 6.0 million per port)

Includes:

- 5G campus network (from PORTABLE 5.0 data)
- V2X communication infrastructure
- Digital twins for port and process modeling
- Interfaces for autonomous truck/train handling
- Full multimodal integration (road/rail/ship)

Justification:

- 5G infrastructure cost directly from PORTABLE 5.0
- scaling up for automation-readiness, based on Hamburg or analogous medium port digital plans

Payback periods typically range 3-5 years through operational efficiency gains, reduced personnel costs, and improved throughput capacities. Rail integration components often show faster payback due to higher volume capacity and reduced environmental compliance costs (based on McKinsey: automation in ports, global sector study).

12.2. Macroeconomic Benefits

Employment Effects: While automation may enable long-term personnel reductions, the implementation phase creates high-skilled jobs in IT, system integration, and digital port management.

Regional Development: Improved port efficiency strengthens regional supply chains and industrial clusters, particularly in areas like renewable energy and circular economy. Enhanced rail connectivity particularly benefits regional industrial development by providing sustainable transport alternatives.

Export Competitiveness: More efficient ports reduce logistics costs and improve the competitiveness of European exports in global markets.

13. Risk Management and Challenges

13.1. Technical Risks

Legacy System Integration: Existing port infrastructures may present compatibility issues with new digital systems. Rail systems present particular integration challenges due to different technical standards and safety requirements. Solutions include gradual migration and gateway technologies for system bridges.

Cybersecurity Vulnerabilities: Increasing digitalization expands the attack surface for cyber threats. Robust security architectures with network segmentation and continuous monitoring are essential.

Technology Obsolescence: Rapid technological development can lead to premature system obsolescence. Modular, open architectures and regular technology roadmap reviews minimize this risk.

13.2. Operational Challenges

Personnel Resistance: Employees may perceive automation as a threat to their jobs. Comprehensive communication, training, and retraining are critical for successful transformation**.**

Intermodal Coordination Complexity: Managing coordination between different transport modes with varying operational requirements, schedules, and technical systems requires sophisticated management approaches and stakeholder engagement.

Data Quality and Integration: Inaccurate or incomplete data can impair system performance. Robust data validation and cleansing are necessary.

Regulatory Compliance: Evolving regulations for autonomous systems and data protection require continuous monitoring and adaptation.

14. Future Perspectives and Emerging Technologies

14.1. Autonomous Vehicles and Drones

Autonomous Trucks: The Hamburg TruckPilot project successfully demonstrates autonomous truck operations in controlled port environments. German legislation already enables autonomous vehicles in designated operational areas, opening implementation opportunities for SMPs.

Autonomous Rail Systems: Development of autonomous train operations within port areas, building on Digital Automatic Coupling (DAC) technology and smart rail systems. Integration with port traffic management enables fully automated intermodal transfers.

Drone Integration: Airborne systems can complement infrastructure inspection, security monitoring, and environmental monitoring. MicroVision's lidar technology is already revolutionizing port and yard automation through precise 3D mapping.

14.2. Artificial Intelligence and Machine Learning

Predictive Analytics: Advanced AI models can predict maintenance needs, traffic patterns, and operational anomalies with increasing accuracy.

Multimodal AI Coordination: Large Language Models (LLMs) for integration of unstructured data from multiple transport modes, including weather conditions, market reports, and regulatory updates affecting both road and rail operations.

Computer Vision: Advanced image analysis for automatic damage detection, quality control, and security monitoring across all transport modes.

14.3. Blockchain and Distributed Ledger

Supply Chain Transparency: Blockchain technology can enable end-to-end transparency in supply chains and reduce counterfeiting and document fraud.

Intermodal Smart Contracts: Automated contract execution for integrated port, rail, and trucking services, enabling seamless multimodal transport booking and payment systems.

Interorganizational Trust: Trustless collaboration between different port stakeholders including rail operators, trucking companies, and terminal operators without central authority.

15. Conclusion

Digital traffic management represents a practical, cost-effective pathway for small and medium-sized ports to begin their digital transformation journey while immediately improving operational efficiency and environmental performance. By serving as the technological foundation for future multimodal automation, these systems enable SMPs to contribute meaningfully to EU modal shift and sustainability goals while maintaining competitiveness in evolving intermodal supply chains.

The proposed approach leverages existing infrastructure, provides immediate operational benefits, and creates the data-driven decision-making capabilities essential for modern multimodal port management. True transformation requires digital traffic management systems that encompass both road and rail transport, enabling the seamless coordination that underpins successful modal shift initiatives. Through strategic implementation and appropriate policy support, digital traffic management can transform SMPs into efficient, sustainable, and future-ready components of Europe's maritime infrastructure.

For SMPs to fulfill their critical role in a climate-neutral, digitally enabled European transport network, digital traffic management must fully embed the management and optimization of rail container flows alongside truck movements. Port digitalization initiatives that foster integrated, intermodal, and transparent management of hinterland connections will be key for economic and environmental sustainability.

This initiative aligns perfectly with the EU Port Strategy's emphasis on digitalization, sustainability, and competitiveness while addressing the specific needs and constraints of small and medium-sized ports that form the backbone of Europe's regional supply chains. With expected investment needs of 80 billion Euros for European ports in the next ten years, the time is ripe for comprehensive support of digital transformation initiatives that advance both economic competitiveness and environmental sustainability.

The integration of rail freight digitalization into small and medium port operations represents not just a technological upgrade, but a strategic imperative for achieving the EU's modal shift objectives and climate neutrality goals. By 2030, ports implementing comprehensive multimodal digital traffic management systems can expect to see measurable improvements in throughput efficiency, modal shift achievement, emissions reduction, and operational resilience that will position them as competitive, sustainable gateways in the intermodal supply chain network of the future.

Bibliography

AIT – Austrian Institute of Technology, 2025. Digital Transformation and the Next Wave of Port Efficiency. BCG/TIC4.0-Studie. Boston Consulting Group [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.bcg.com/publications/2025/digital-transformation-next-wave-port-efficiency

Addamo, A. et al., 2022. The EU Blue Economy Report 2022. Publications Office der EU [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://op.europa.eu/en/publication-detail/-/publication/94e82771-da27-11ec-a95f-01aa75ed71a1

Antolini, A., 2025. Common – EU decarbonization policy: Study on greening EU ports. JTTRI, Tokio [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.jttri.or.jp/topic_europe_2025Jan-01.pdf

AnyLogic Company, 2025. Port and Terminal Simulation Software. AnyLogic Resources [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.anylogic.com/ports/

AnyLogic Company, 2025. Optimizing Rail Operations of a Container Port - NSW Ports Case Study [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.anylogic.de/resources/case-studies/optimizing-rail-operations-of-a-container-port/

AnyLogic Company, 2025. Simulation at scale: how TNPA standardized capacity planning [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.anylogic.de/blog/simulation-at-scale-how-tnpa-standardized-capacity-planning/

BRIDGE2HE-Konsortium, 2022. Horizon Europe Glossary – A simple guidance through HEU terminology. APRE (Hrsg.) [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.research.org.cy/horizoncy/wp-content/uploads/Horizon-Europe-Glossary.pdf

Belmoukari, B. et al., 2023. Smart port: A systematic literature review and bibliometric analysis. European Transport Research Review, Vol. 15 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.sciencedirect.com/science/article/pii/S2092521223000354

CORDIS, 2024. Creating the port of the future – Ergebnisse des Projekts PortForward. Europäische Kommission [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://cordis.europa.eu/article/id/442407-creating-the-port-of-the-future

DB Cargo, 2024. Digital automatic coupling ready to enter service. Logistics News [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.dbcargo.com/rail-de-en/logistics-news/digital-automatic-coupling-ready-to-enter-service-12829256

DLR – Deutsches Zentrum für Luft- und Raumfahrt, 2025a. FuturePorts – Enabling the future of waterborne transportation focused on ports. Köln [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.dlr.de/en/research-and-transfer/projects-and-missions/futureports

DLR – Deutsches Zentrum für Luft- und Raumfahrt, 2025b. LDACS – Communications for aviation. Köln [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.dlr.de/en/kn/research-transfer/projects/safety-and-efficiency-for-aviation/ldacs-communications-for-aviation

DLR – Deutsches Zentrum für Luft- und Raumfahrt, 2025c. Strategy and Programme – Transport Research. Köln [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.dlr.de/en/research-and-transfer/transport/strategy-and-programme

ECTRI – European Conference of Transport Research Institutes, 2025a. Freight & Logistics Thematic Group. Brüssel [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.ectri.org/about-ectri/structure/them-groups-task-forces/freight-logistics/

ECTRI – European Conference of Transport Research Institutes, 2025b. Traffic Management & Modelling Thematic Group. Brüssel [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.ectri.org/about-ectri/structure/them-groups-task-forces/traffic-management-modelling/

ECTRI – European Conference of Transport Research Institutes, 2025c. New ECTRI Thematic Groups' leadership take the helm. Pressemitteilung, 06.09.2023 [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.ectri.org/2023/09/06/new-ectri-thematic-groups-leadership-take-the-helm/

ECTRI – European Conference of Transport Research Institutes, 2025d. ECTRI replies to EC's Call for Evidence on the European Strategy for Research and Technology Infrastructures. Brüssel [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.ectri.org/2025/06/04/ectri-replies-to-the-european-commissions-call-for-evidence-on-the-european-strategy-for-research-and-technology-infrastructures/

Ehiagwina, A., 2021. Application of Mixed Simulation Method to Modelling Port Traffic. PhD Thesis, Liverpool John Moores University [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://researchonline.ljmu.ac.uk/id/eprint/15592/1/2021AugustineEhiagwinaPhD%20.pdf

Europe's Rail, 2022. Digital Automatic Coupling (DAC) – the backbone for full digital rail freight train operations in Europe. Factsheet [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://rail-research.europa.eu/wp-content/uploads/2021/04/DAC-Factsheet_EN.pdf

Europe's Rail Joint Undertaking, 2025. Flagship Project 5: TRANS4M-R - Transforming Europe's Rail Freight [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://rail-research.europa.eu/rail-projects/fp5-trans4m-r/

European Commission, 2025a. Commission sets course for future EU ports and maritime industry – Pressemitteilung 01.07.2025. Brüssel: DG MOVE [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://transport.ec.europa.eu/news-events/news/commission-sets-course-future-eu-ports-and-maritime-industry-2025-07-01_en

European Commission, 2025b. Scientific support for EU policies. Brüssel: DG Research & Innovation [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://research-and-innovation.ec.europa.eu/strategy/support-policy-making/scientific-support-eu-policies_en

European Commission, 2025c. Widening participation and strengthening the European Research Area – Horizon Europe Work Programme 2025 (Teil 11). Brüssel [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://sciencebusiness.net/sites/default/files/inline-files/HORIZON-WIDERA-2025_10_04_2024_Advanced%20draft.pdf

European Commission, 2024a. Call for evidence – Evaluation der Vergaberichtlinien. Brüssel: DG GROW [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://single-market-economy.ec.europa.eu/news/commission-launches-call-evidence-and-public-consultation-evaluation-public-procurement-directives-2024-12-13_en

European Commission, 2024b. Trans-European Transport Network (TEN-T) - Regulation (EU) 2024/1679 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

European Court of Auditors, 2023. Special report 08/2023: Intermodal freight transport - European Union. Luxembourg [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.eca.europa.eu/lists/ecadocuments/sr-2023-08/sr-2023-08_en.pdf

European Parliament, 2018. Trans-European Transport Network (TEN-T). EPRS Briefing [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.europarl.europa.eu/RegData/etudes/BRIE/2018/615664/EPRS_BRI(2018)615664_EN.pdf

Federal Ministry for Digital and Transport (BMDV). (2024). PORTABLE 5.0 – Digital transformation of small and medium-sized ports – Supporting sustainable, cross-regional and multimodal transport chains. Official project brief. Total project volume: €4.5 million (80% publicly funded). Project duration: 01/2022–06/2024.Felt, U. et al., 2007. Taking European Knowledge Society Seriously – Report of the Expert Group on Science and Governance. Luxemburg: Publ. Office der EU [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://sts.univie.ac.at/fileadmin/user_upload/i_sts/Ueber_uns/pdfs_Felt/taking_european_knowledge_society_seriously.pdf

Gerken, P. et al., 2022. Digitalization of rail freight transport. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 33, pp. 403-435 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.econstor.eu/bitstream/10419/267194/1/hicl-2021-33-403.pdf

Hapag-Lloyd, 2025. The Smartest Ports in the World: From Smart Ideas to Global Leaders [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.hapag-lloyd.com/de/online-business/digital-insights-dock/insights/2025/06/the-smartest-ports-in-the-world-from-smart-ideas-to-global-leade.html

Haskoning DHV, 2025. A sea change of digital transformation at European Ports. Panasonic Connect Blog [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://eu.connect.panasonic.com/gb/en/blog/sea-change-digital-transformation-european-ports

ITF-OECD, 2021. Container Port Automation: Impacts and Implications. OECD/ITF Report [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.itf-oecd.org/sites/default/files/docs/container-port-automation.pdf

Interreg MED – PSAMIDES, 2022. Ports in Transition – White Paper. Port of Sète (Hrsg.) [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://euroregio.eu/wp-content/uploads/D5.3.1-PSAMIDES_White-Paper_EN_reduit.pdf

Interreg NSR – NON-STOP, 2023. Sustainability Projects – Niedersachsen Ports. Oldenburg [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.nports.de/en/sustainability/sustainability-projects

Konar-Skourski, M. et al., 2021. A Digital or Sustainable Small and Medium-Sized Port? Transport and Telecommunication Journal, 22(3) [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://sciendo.com/article/10.2478/ttj-2021-0026Titel anhand dieser DOI in Citavi-Projekt übernehmen

Mathews, A. S., 2025. Sustainable Practices in Port Operations. Rcademy Blog [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://rcademy.com/sustainable-practices-in-port-operations/

Mathisen, T.A., Hanssen, T.E.S., 2014. The Academic Literature on Intermodal Freight Transport. Transportation Research Procedia, 3, pp. 611-620 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.sciencedirect.com/science/article/pii/S2352146514002038 mfame.guru, 2025. EU Launches Strategic Dialogues to Shape Future Ports and Maritime Industry Policies. 04.07.2025 [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://mfame.guru/eu-launches-strategic-dialogues-to-shape-future-ports-and-maritime-industry-policies/

NIST, 2024a. The NIST Cybersecurity Framework (CSF) 2.0. NIST CSWP 29, February 26, 2024 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.29.pdf

NIST, 2024b. NIST Cybersecurity Framework 2.0: Resource & Overview Guide. NIST SP 1299 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1299.pdf

NPorts – Niedersachsen Ports, 2025. Sustainability Projects (Projektübersicht). Wilhelmshaven [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.nports.de/en/sustainability/sustainability-projects

Panasonic TOUGHBOOK, 2025. Digital Transformation Insight – European Ports. Blogeintrag 02.07.2025 [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://eu.connect.panasonic.com/gb/en/blog/sea-change-digital-transformation-european-ports

Port of Kristiansand et al., 2023. NON-STOP Smart Sediment and Water Management – Projektbeschreibung. Interreg NSR [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://northsearegion.eu/media/22427/thesis_digital-transformation-of-small-and-medium-sized-ports.pdf

Rimkutė, D., 2015. How do European institutions use scientific expertise? Ideas on Europe Blog [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://era.ideasoneurope.eu/2015/07/06/european-institutions-use-scientific-expertise/

Sciendo, 2023. Digital or Sustainable Small and Medium-Sized Port? Article PDF [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://sciendo-parsed.s3.eu-central-1.amazonaws.com/64736ea94e662f30ba53e060/10.2478_rtuect-2023-0035.pdf

Transport.ec.europa.eu, 2024. New study published on greening European sea ports – News 17.12.2024. Brüssel: DG MOVE [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://transport.ec.europa.eu/system/files/2017-12/2017-10-dina.pdf

U.S. Naval Institute, 2024. Smart Ports – Maritime Intelligence's Blind Spot. Proceedings, December 2024 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.usni.org/magazines/proceedings/2024/december/smart-ports-maritime-intelligences-blind-spot

Union for the Mediterranean, 2024. ENSURE – EuropeaN Sustainable Urbanisation through port city regeneration. ESPON Programme [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://www.espon.eu/projects/ensure-european-sustainable-urbanisation-through-port-city-regeneration

Wang, Y. et al., 2024. Digital twin-driven safety management and decision support approach for port operations and logistics. Frontiers in Marine Science, Vol. 11 [Online]. [Zugriff am: 21.07.2025] Verfügbar unter: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1455522/fullTitel anhand dieser DOI in Citavi-Projekt übernehmen

Zhang, Y. et al., 2022. Digital Inland Waterway Area and Digital Multimodal Nodes – EU Study. DG MOVE [Online]. [Zugriff am: 20.07.2025] Verfügbar unter: https://transport.ec.europa.eu/system/files/2017-12/2017-10-dina.pdf

List of abbreviations

AFIR - Alternative Fuels Infrastructure Regulation

AGV - Automated Guided Vehicle

AI - Artificial Intelligence

AIS - Automatic Identification System

API - Application Programming Interface

ATO - Automatic Train Operation

ATP - Automatic Train Protection

BIM - Building Information Modeling

CAD - Computer-Aided Design

CAPEX - Capital Expenditure

CCS - Cybersecurity

CCTV - Closed-Circuit Television

CEF - Connecting Europe Facility

CERTH/HIT - Centre for Research and Technology Hellas / Hellenic Institute of Transport

CINEA - European Climate, Infrastructure and Environment Executive Agency

CISE - Common Information Sharing Environment

CNN - Convolutional Neural Network

CPA - Common Positioning Agreement

CSF - Cybersecurity Framework

CTP - Common Transport Policy

DAC - Digital Automatic Coupling

DAK - Digitale Automatische Kupplung

DDoS - Distributed Denial of Service

DFTO - Digital Freight Train Operation

DG MOVE - Directorate-General for Mobility and Transport

DHC - District Heating and Cooling

DLR - Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)

DT - Digital Twin

EC - European Commission

ECTRI - European Conference of Transport Research Institutes

EDDP - European DAC Delivery Programme

EEZ - Exclusive Economic Zone

EFIP - European Federation of Inland Ports

EPF - European Ports Forum

EPP - European Port Policy

ERTMS - European Rail Traffic Management System

ESPO - European Sea Ports Organisation

ETCS - European Train Control System

ETS - Emissions Trading System

EU - European Union

EU-Rail - Europe's Rail Joint Undertaking

FAL - Facilitation of International Maritime Traffic

FDFTO - Full Digital Freight Train Operation

FEPORT - Federation of European Private Port Companies and Terminals

GHG - Greenhouse Gas

GMDSS - Global Maritime Distress and Safety System

GNSS - Global Navigation Satellite System

GPS - Global Positioning System

HPA - Hamburg Port Authority

HVAC - Heating, Ventilation, and Air Conditioning

IALA - International Association of Marine Aids to Navigation and Lighthouse Authorities

ICT - Information and Communications Technology

IEC - International Electrotechnical Commission

IMO - International Maritime Organization

ISO - International Organization for Standardization

IT - Information Technology

ITS - Intelligent Transport Systems

IoT - Internet of Things

KMH - Kleine und mittlere Häfen (Small and Medium-sized Ports)

KPI - Key Performance Indicator

KTI - Institute for Transport Studies (Sweden)

LED - Light-Emitting Diode

LOGINK - National Transportation and Logistics Public Information Platform (China)

LRIT - Long-Range Identification and Tracking

LSTM - Long Short-Term Memory

LiDAR - Light Detection and Ranging

MCP - Maritime Connectivity Platform

MEPs - Members of the European Parliament

ML - Machine Learning

MRS - Mandatory Reporting System

MTU - Master Terminal Unit

NIST CSF 2.0 - National Institute of Standards and Technology Cybersecurity Framework Version 2.0

OCR - Optical Character Recognition

OPEX - Operational Expenditure

ORE - Offshore Renewable Energy

OT - Operational Technology

PCS - Port Community System

PLC - Programmable Logic Controller

PMB - Port Managing Body

PMIS - Port Management Information System

PV - Photovoltaic

R&D - Research and Development

RDF - Radio Direction Finding

RFID - Radio Frequency Identification

RIS - River Information System

RTG - Rubber Tired Gantry (crane)

RTU - Remote Terminal Unit

SCADA - Supervisory Control and Data Acquisition

SMP - Small and Medium-sized Ports

SP 800-82r3 - NIST Special Publication 800-82 Revision 3

SSN - SafeSeaNet

SST - Solid State Transformer

TAF TSI - Technical Specification for Interoperability relating to Telematics Applications for Freight

TEN-T - Trans-European Networks-Transport

TG - Thematic Group

TRANS4M-R - Transforming Europe's Rail Freight (FP5 Flagship Project)

TSS - Traffic Separation Scheme

UHF - Ultra High Frequency

V2G - Vehicle to Grid

V2X - Vehicle-to-Everything Communication

VHF - Very High Frequency

VTI - Swedish National Road and Transport Research Institute

VTMIS - Vessel Traffic Management and Information System

VTS - Vessel Traffic Service

ZPMC - Shanghai Zhenhua Heavy Industries Company Limited