Interreg

Co-funded by the European Union

Italy – Croatia

CROSSFREIGHT

D 2.3.1 FIELD OPERATIONAL TESTS IMPACT ASSESSMENT

Joint report by PP3 AIN

Interreg Co-funded by the European Union

Italy – Croatia

CROSSFREIGHT

Project Acronym	CROSSFREIGHT
Project ID Number	ITHR0200487
Project Title:	Cross-border ICT Strategies for freight rail and port logistic integration, optimization, sustainability and security
Start of the project	March 2024
Duration	28 months
Related activity:	Activity 2.3. Field operational tests impact assessment
Deliverable name:	Deliverable D.2.3.1) Prepared for WP2– Field operational tests impact assessment
Type of deliverable	Report
Language	English
Work Package Title	Crossfreight Transferability Analysis
Work Package number	2
Work Package Leader	PP3 AIN
Status	Finalized
Author (s)	PP3 AIN
Version	Final
Due date of deliverable	April 2026
Delivery date	24th April 2026

Table of contents

1. Introduction

This report provides a comprehensive assessment of the impacts generated through the Field Operational Tests (FOTs) conducted in Work Package 2 of the CROSSFREIGHT project. While Deliverable D.2.2.1 documented what was executed during each pilot, the present Deliverable D.2.3.1 evaluates how these tests performed and what impacts they generated across multiple dimensions.

The assessment synthesizes impacts from:

- usability,
- process improvements,
- rail & logistics market effects,
- macroregional (EUSAIR) relevance,
- EU policy alignment.

Impacts have been evaluated using the FESTA methodology, structured KPI analysis, qualitative stakeholder feedback, operational logs, and cross-node comparison. Data sources include the technical and operational reporting in D.2.2.1, pilot questionnaires submitted in WP3, and results documented in Deliverable D.3.1.1.

2. Methodological Framework

The methodology applied in this Deliverable was designed to ensure a coherent, reliable and comparable assessment of all Field Operational Tests conducted within the CROSSFREIGHT project. It follows a structured evaluation logic rooted in the FESTA

methodological approach, adapted to the specific characteristics of multimodal railway–port environments. The overall aim was to analyse how each ICT solution performed in real operational conditions, how it influenced existing processes, and what measurable or qualitative impacts emerged during and after the testing phase.

The assessment began with a systematic collection of evidence from all pilot nodes. Each partner was asked to complete a detailed technical and operational questionnaire, which served as the central instrument for gathering data on how their ICT module was developed, integrated, executed and validated in practice. This questionnaire provided a harmonised framework that enabled partners to document the entire lifecycle of their pilot, including the original requirements, technical specifications, organisational arrangements, testing procedures and the results observed during implementation. Through this unified format, the project ensured that all pilots—despite being technologically diverse—were evaluated under the same analytical principles.

The evaluation combined both quantitative and qualitative elements. Quantitative data included system logs, performance indicators, KPI measurements, time-based operational records, error rates, and other metrics extracted directly from the ICT tools or from operational logs maintained by the partners. Qualitative data consisted of user observations, operator feedback, experience from shunting teams, maintenance technicians, safety experts, and port or terminal staff. This dual perspective allowed the methodology to capture not only the technical performance of each tool but also the human experience of using it—an essential aspect for assessing long-term usability and adoption potential.

The assessment process also examined how each pilot aligned with the "TO BE" scenarios defined earlier in Work Package 2. This involved comparing the planned improvements with those actually observed during the Field Operational Tests. Partners were therefore encouraged to reflect critically on deviations from original plans, unexpected challenges, or additional needs that emerged during real-world testing. These reflections helped validate the coherence and relevance of the solutions and provided valuable insights into their scalability and transferability.

To reinforce the credibility of the assessment, the methodology incorporated cross-validation through partner meetings, internal reviews and the verification of consistency across submissions. Where possible, technical findings were supported by visual evidence, such as screenshots, system demonstrations, video documentation or structured logs produced during testing. Although some nodes were still in the process of finalising their visual material, each partner provided sufficient evidence to confirm the operational viability of the tested ICT tools.

Overall, the methodology ensured a balanced examination of technical performance, organisational readiness, operational impacts, and strategic relevance. By integrating multiple sources of evidence, technical, behavioural and organisational, it provided foundation for understanding not only whether each ICT solution worked as intended, but also how it influenced daily operations, decision-making, safety, coordination and the broader objectives of the CROSSFREIGHT project. The resulting analysis forms a comprehensive basis for identifying the impacts of the Field Operational Tests and for supporting future transferability and scale-up across the Adriatic region and beyond.

3. Summary of Pilots Included in Impact Analysis

The following pilot nodes from D.2.2.1 are included in the impact evaluation:

Partner	Node	Type of ICT Solution	Core Focus
LP1 ITL	Ravenna	Advanced optimisation engine	Shunting optimisation
PP2 Adriafer	Trieste	PCS–TrainShunt integration	Digital shunting management
PP3 AIN	National	Digital case management	Railway safety documentation
PP4 ERF	Venice–Marghera	ICT for siding condition monitoring	Predictive maintenance
PP6 Sangritana	Abruzzo	IoT-based tracking + cameras	Traffic & security monitoring
PP7 LUŠ Šibenik	Sjeverna luka Split	Low-cost Excel-based tool	Capacity & loading optimisation
PP8 Transagent	Rijeka	Freight Information System (FIS)	Real-time train operations

4. Usability Analysis

Across all nodes, usability impacts were highly positive.

4.1 User acceptance

- LP1 ITL gathered user feedback during demonstration sessions held with relevant stakeholders and during training sessions with shunting operators.
    - The first stakeholder meeting was held on 2nd of March and involved the Port of Ravenna Authority, the terminal operators of the port area and a representative of the customs office. The focus of the meeting was the Rail Management System of the port as a whole. The stakeholders attending the meeting were not the primary users of the specific module that was developed during the project but they welcomed the improvement and showed interest in it. It can be concluded that the port community accepts this kind of technological innovation.
    - On the 24th of April, feedback was gathered from Bologna Freight Village – the intermodal node selected for the transferability analysis as a potential end user. They deemed the tool useful but stated that at this point it could not be applied at the freight village because they do not currently have any shunting management software to integrate it with. It was concluded that the tool would be useful for an intermodal terminal of that size but the freight village does not yet have the technical maturity to adopt it.

- Between March and April, two training sessions were held with the shunting operators. During the meeting, the operators could test the ICT solution and ask questions. This session allowed ITL to gather a series of valuable user feedback and some criticalities emerged, namely:
  - The software only makes it possible to handle entire trains, but it would be useful to handle single wagons separately.
  - The software allocates available time slots based on the availability of the staff or locomotives, but it does not consider that sometimes it is the terminal operator to indicate the time slot when they wish to receive the train.
  - When a train gets cancelled, but it has already been coupled with another train, it is impossible to modify this pair of trains, and the user needs to create a new combination of trains. However, sometimes these modifications occur when the shunting process has already started, so more flexibility is needed from the software.

- PP2-Adriafer (Port of Trieste): Operators at Trieste reported significantly clearer interfaces and streamlined workflows. User acceptance for the integrated Sinfomar PCS and Trainshunt digital platform was evaluated through interviews and operational tracking of the primary key users (Adriafer's rail planners and ground shunting coordinators).

- High Operational Endorsement: The transition to automated web-service communications received immediate positive buy-in. Rail planners praised the "Digital Shunting Suppression" module, which eliminated double data entry and drastically reduced communication errors during sudden schedule updates.
- System Trust: The real-time synchronization of train composition data via the GTR-GCSP interoperability framework established high trust among users, who could rely on a single, shared wagon database rather than reconciling mismatched Excel files or paper.
- Perceived Utility: Operators highlighted that having automated data flows regarding train status significantly minimized administrative bottlenecks in the last mile port operations, ensuring smoother handovers between mainline rail services and port terminal shunting.

- PP3 AIN's investigative staff experienced major improvement in workflow clarity, replacing fragmented spreadsheets with structured modules. The Application for data monitoring in the railway system was met with exceptionally high user acceptance among the investigative staff. Investigators quickly embraced the system because it replaced fragmented Excel spreadsheets with clear, structured modules. Key factors for this positive response included:

  - No More Data Fragmentation: Users appreciated having all accident records, incident logs, and safety documents centralized in a single dashboard.

- Clearer Workflows: The software guides users step-by-step through regulatory reporting, making it easier to ensure all data is complete and compliant.
- Quick Adoption: Because the interface is user-friendly and matches their daily tasks, investigators started entering real data immediately after the training session without resistance.

- PP4 ERF's ICT solution was designed with the involvement of its technical operators, to design and implement a system which already meets their needs for detecting the geometry of switches. This approach also allowed for pre-emptive training of staff in its use.

- PP6 Sangritana operators adapted quickly to IoT-based monitoring once training was finalised.

  The Saletti 4.0 application was reviewed and tested over selected trains at the Operating Room, evaluating through interviews and tracking of the system usage by the operators. The key user acceptance criteria were the following:

  - Perceived usefulness: the digital system, originally evaluated with prejudice, was positively evaluated by the operating users, which could start putting on

planning the trains and digitally assign the shunting locomotives to each train;

- Ease of use: the system was praised for the ease of use, allowing the users to quickly access the various areas of the system with a user-friendly interface;
- Satisfaction: the ease of use and the usefulness perception increase the overall user satisfaction, with identification of areas of improvement in order to make the system even more performing.
- Intention to use: the general plan is to modify the structure of the system to make it even more specific to the needs of Sangritana and keep using it on a regular basis.
- Trust and Reliability: there is a general concern over the reliability of the hardware, though much more reliance on the software part. Considering that the software part is the key element of the system, further steps will have to be taken to improve the reliability and trust over the hardware sensors.

- PP7 Port of Šibenik Authority (LUS) stakeholders appreciated the ease of a low-complexity tool, with short learning curves. User feedback was gathered through direct involvement of the main operational stakeholders during the pilot: Port of Šibenik Authority, Luka Šibenik, and HŽ Cargo. Stakeholders contributed operational data such as train schedules, train IDs, track/time-slot use, loading and unloading information, and feedback on loading accuracy and delays. Feedback was collected through the use of the Excel-based ICT planning tool, regular

operational coordination, and review of the data, charts, tables, and performance indicators generated during the pilot.

The pilot outcomes were positive. The tool improved transparency of operational data, supported better coordination between the port authority, railway operator, and terminal/cargo operator, and enabled more efficient scheduling of trains and use of railway infrastructure. It also helped stakeholders identify potential delays, monitor loading/unloading performance, and assess operational efficiency through KPIs such as train throughput, loading/unloading time, platform utilization rate, train turnaround time, delay rate, and loading accuracy/error rate.

- PP8 – Transagent: After education and testing on the test branch of the system users began to independently work in production. During development FIS (Freight Information System) was built around the agile development method – with user input in mind and changes made according to their feedback. An important point for the direction of the development of the system was optimisation for mobile and touch input devices that were going to be used for data entry, eliminating most of the needs to manually type data into the system. FIS automatically generates and sends e-mail notifications regarding the movement of trains to outside partners, internal work orders to workers, and miscellaneous other types of manual notifications. This reduces the need to directly communicate with partners and workers via phone calls, which decreased the overall workload and increased user satisfaction. Work hours are automatically calculated from users work orders which

reduced the number of errors and time needed to process said data. Interoperability is achieved via communication with HŽI systems using TAF-TSI framework messages. Within FIS all workers have access to their personal work record where they can find all the documents they need at work in a digital format which includes: regulatory documents, rulebooks, laws, timetables... Access to their personal digital data allows quick and efficient cooperation with security inspectors because workers don't have to carry around the physical documents, instead presenting their digital versions that they always have access to within the system. After training and testing FIS has been in production phase since 01.05.2026. Overall implementation of FIS has resulted in increased partner and worker satisfaction.

4.2 Training and onboarding

All partners completed training as required in D.2.2.1, section "Training sessions and organisational arrangements."

Minimal additional support was required.

LP1 ITL carried out two training sessions during the pilot action. The first one was introductive and no questions emerged, whereas the second one allowed the users to try the tool themselves. Since one of the shunting operators could not be present at the training sessions, and also to guarantee the continuity of the tool, a short training video was prepared, in addition to the user manual initially planned.

PP2-Adriafer (Port of Trieste): To ensure a structured transition to the newly developed ICT modules, a formal training strategy was executed jointly by Adriafer's involved team and Info.era (the technical provider).

- Onboarding Strategy: The training program was designed around the designated key users (chief rail planners and operational coordinators) to foster an internal training.
- Execution of Technical & Operational Sessions: *Session 1: Technical Walkthrough & Software Interfaces.* Led by Info.era, this session focused on introducing the updated web-service endpoints, data validation screens, and the automated cancellation protocols. *Session 2: Field Operational Simulation.* A practical hands-on session where rail planners simulated real cases, such as managing late train arrivals and live synchronization of single wagon data.

PP3 AIN: Upon completion of the development of the Application for data monitoring in the railway system on December 5, 2025, the contractor conducted in person training of AIN users (investigative staff). The Application is user-friendly to understand, use and enter data, and after the training, AIN users immediately continued entering data.

PP4 - Esercizio Raccordi Ferroviari di Porto Marghera S.p.A.: Operations staff collaborated from the early stages of software analysis and design. This minimized on-site training time. Special attention was paid to the system's ergonomics, ensuring its immediacy and ease of use, both in data entry and visualization.

PP6 Sangritana conducted training courses for the operating team, so as to ensure the full understanding of the system capabilities.

- Structured Onboarding Process: the onboarding process was made of the introduction of the new solution to the operating team, with technical courses and sessions, guided practice and the start of transition towards independent usage.
- Technical Courses & Session: clear learning objectives were identified, with role-based training both impersonating the Terminal users, the Rail Operator and the Shunting Operator. During the test both sandbox tests were conducted and a real case scenario. A short video was made as a video tutorial.

PP7 – Port of Šibenik Authority (LUS): The partner carried out the training sessions in person, as this was the easiest and most effective approach for the pilot. Since the ICT solution was based on a simple Excel-based planning tool, the training was organised as a practical hands-on session with the main stakeholders involved in railway and port operations. During the session, participants were shown how to enter train schedules, allocate rail tracks and time slots, monitor loading and unloading operations, and read the tables, charts and KPIs generated by the tool.

This approach allowed users to ask questions directly, test the tool with real operational examples, and quickly understand how it could support their daily work. In-person training was also suitable because the pilot involved a limited number of local stakeholders who were directly involved in coordination, data provision and testing activities.

PP8 – Transagent: FIS was designed with three key subsystems in mind: Development, Testing, and Production. While in development users had the chance to fully test all the system capabilities on the test branch, providing feedback and suggestions for further development and implementation of new features. Most of the constructive feedback provided by users was evaluated and, in some shape or form, implemented into the final solution. Testing was done on real world examples and cases.

4.3 Human-factor insights

- Manual data-entry remains a challenge in Šibenik and Sangritana.
- Practical testing (hands-on testing) enabled users to adopt new work processes more easily.

Overall usability impact**:** High, with strong acceptance across operators, planners, administrative staff and external stakeholders.

LP1 ITL: Some important considerations emerged during the testing phase and the training sessions. On one hand, the automation significantly reduced the possibility for human error, as the amount of data that needs to be manually inserted has been reduced to a minimum. On the other hand, the operators predicted no reduction in the working time at the initial phase of the adoption, as there will likely be a learning curve. Once the operators will have learnt to use the module, however, there will be significant savings in time spent on scheduling the shunting operations.

PP2-Adriafer (Port of Trieste): Analyzing the human-factor insights during the Field Operational Tests (FOT) highlighted crucial cognitive and operational enhancements brought by the digital solution:

- Drastic Reduction in Cognitive Load: Previously, port shunting coordinators faced intense mental fatigue caused by constant out-of-band phone calls and uncoordinated email threads to manage late train suppressions. By moving these operations to a digitized cancellation framework within Sinfomar/Trainshunt, the stress associated with real-time planning was significantly mitigated.
- Minimization of Human Error: The automated flow of train composition data directly into the active shunting modules removed manual transcription mistakes.
- Interface Ergonomics & Usability Tweaks: Targeted front-end and user interface (UI) refinements were identified and applied during the internal testing loops. These adjustments specifically improved data visualization fields for long train sets, ensuring that the shunting data displayed was clear, intuitive, and readily actionable for operators under tight time constraints.

PP3- AIN: The human-factor analysis for the AIN pilot focused primarily on how the shift from legacy spreadsheet tracking to a dedicated digital application affected the cognitive workload and diagnostic accuracy of safety investigators:

- Lower Cognitive Load: Investigators reported less mental fatigue. Previously, they had to open, enter, and save data in 6 different Excel spreadsheets. Now they have all data in one place, 6 modules where they enter data.

- Fewer Data Errors: The structured validation fields within the application drastically lowered the human-error rate during data entry, preventing conflicting records.
- Increased Confidence: The ease of use boosted the team's confidence. Replacing outdated tools with a modern system created a more proactive attitude toward digital record-keeping.

PP4 - Esercizio Raccordi Ferroviari di Porto Marghera S.p.A.: In a sensitive context like railway infrastructure maintenance, the human factor must be taken into account. Monitoring operations performed in the field, even in variable weather conditions, the management of data collection and recording equipment, human error, and other factors external to the work environment can impact the quality of the survey. To minimize these effects, the system was also designed to serve as a support tool for the field operator in the event of an incorrect measurement. This minimizes the propagation of errors, making the system more robust and consistent.

PP6 Sangritana during the Field Operational Test (FOT) identified crucial cognitive and operational enhancements that were raised by the digital solution:

- Increase in the perceived value of the solution: crossing the digital innovation resistance, the perceived value of the solution lied on the reduction of the time and paper needed to perform shunting operations. With the digital assignment of wagons, it was possible to create a pre-loading list and pre-train list;
- Reduction of the Cognitive Load: the shunting operators and the operating staff, especially in the control room, were exposed to an intense mental fatigue caused by the complexity of the information handled and on the number of variables to

monitor through different portals, paper and emails. With one single system bearing the full pack of material, the user experience got better and cognitive load was reduced.

- The self-efficacy of the solution improved the confidence of the users, also improved by the ease of use of the solution.
- The emotional response was important, keeping up the curiosity over the system and low the frustration, by keeping the platform easy and straight.
- The trust over the software was quite high, while there is still work to do over the acceptance of the hardware monitoring, which is still causing resistance to use. The key aspect will be to conduct stress test over the devices to improve the perception of automatic status changes of trains passing over the sensors.

PP8 – Transagent:

Usage of the system identified several improvements in both work operations, and reduced error rates. FIS allows for automatic conversion of several different train composition documents into a use ready format, thus reducing the need for manual data entry and speeding up dispatchers' work. Train drivers enter their data through a mostly touch interface thus reducing the need for them to manually type in data. This reduces their overall workload and allows them to better focus on their assigned tasks. Automatic calculations of work hours yielded positive results with increased transparency and ease of access for workers.

5. Process Improvements

Across all CROSSFREIGHT pilot nodes, the implementation of the Field Operational Tests resulted in clear and consistent improvements in the efficiency, accuracy and overall quality of operational processes. These enhancements, documented in detail in Deliverable D.2.2.1, reflect the transformative effect that digitalisation can have on both technologically advanced and less mature intermodal environments. The D.2.2.1 is including a detailed analysis of KPIs and this paragraph draws the conclusions based on that. In nodes equipped with more developed digital infrastructures, the improvements were particularly evident in the transition from manual, fragmented communication methods to structured, automated and data-driven operational workflows. In Ravenna, for example, the new optimisation system enabled automated planning, more precise allocation of resources and a reduction in operational bottlenecks. This led to an increase in reliability and capacity without adding pressure to the workload of operational teams. A comparable shift occurred in Trieste, where the integration between TrainShunt and the Sinfomar PCS eliminated manual data exchanges and significantly improved the transparency, speed and accuracy of shunting-related information flows.

At pilot sites with initially lower levels of digital maturity (such as the Port of Šibenik) the improvements manifested primarily through the introduction of structured workflows, standardised daily reporting and greater consistency in data entry. Even though the solution was intentionally simple, the positive effects on internal coordination and procedural discipline were substantial. The pilot replaced unstructured, inconsistent record-keeping practices with harmonised templates and clearly defined responsibilities,

enabling smoother communication between the port authority, railway operators and other stakeholders. Similarly, the implementation of real-time tracking and security monitoring in the Sangritana rail compound enhanced the efficiency of traffic management along the 12-kilometre industrial corridor. The system allowed operators to react more quickly to operational events, identify congestion more precisely and ensure a significantly higher level of safety, both in terms of movement supervision and protection of stationary rolling stock.

In Venice–Marghera, the introduction of a digital solution for monitoring the condition of railway sidings resulted in major improvements in the organisation of maintenance activities. The structured collection, centralisation and analysis of data on infrastructure components enabled earlier detection of anomalies, faster identification of maintenance needs and better coordination between maintenance units and shunting operations. This represents an important step toward predictive maintenance, which not only reduces downtime but also enhances the safety and continuity of rail traffic. At the national level, AIN's transition from Excel-based records to a unified digital application significantly improved the transparency, consistency and timeliness of accident and incident reporting. The digital workflow ensures that investigative procedures follow a clear, orderly structure, reducing administrative burdens and improving overall quality control of safety documentation.

Rijeka's FIS platform also demonstrated clear strengthening of operational processes, particularly in enhancing coordination between railway operators, infrastructure managers and terminal personnel. By consolidating technical and financial indicators into

a single digital environment, the system enabled more predictable operations, clearer communication channels and improved alignment of internal planning processes. The availability of real-time information on train movements reduced communication errors and operational delays, addressing longstanding coordination challenges at this busy intermodal node.

Overall, the process improvements observed across all CROSSFREIGHT pilot sites demonstrate that digitalisation accelerates, clarifies and strengthens operational workflows, regardless of the complexity or size of the node. The shift from reactive to proactive management became evident in all contexts: operators gained timely access to accurate information, errors were reduced, and stakeholder cooperation became more structured and consistent. These results highlight that digital transformation not only enhances technical performance, but also fosters a culture of efficiency, predictability and accountability—laying the foundation for further optimisation, interoperability and long-term sustainability of rail-port systems in the Adriatic macro-region.

6. Impacts on Rail & Logistics Market

The Field Operational Tests carried out within the CROSSFREIGHT project produced clear and meaningful impacts on the functioning of the rail and logistics market across all participating nodes. By introducing digital tools that replaced fragmented, manual, and often inconsistent communication practices, the pilots improved the predictability of operations and strengthened the competitiveness of rail freight within multimodal supply chains. The streamlined access to reliable and timely information was designed to help

mitigate operational uncertainties, thereby supporting optimized resource allocation and accelerating response mechanisms during disruptions. In ports like Ravenna and Trieste, where rail volumes are high and operations complex, the optimisation tools helped stabilise workloads while supporting increased throughput. This had a direct positive influence on the perceived reliability of rail services and their attractiveness to shippers.

Furthermore, digitalisation contributed to a more transparent logistical environment. In Rijeka, the introduction of the Freight Information System improved the flow of information between terminal operators, the infrastructure manager, and railway companies, reducing bottlenecks associated with miscommunication or delayed updates. Sangritana's real-time monitoring system enhanced the management of industrial freight flows by ensuring that train movements along the 12-kilometre corridor could be closely supervised, thereby reinforcing safety and operational reliability. Even in small-volume environments such as Šibenik, the introduction of structured recording practices supported more accurate performance tracking and improved overall cargo-handling efficiency.

These advancements strengthen the strategic positioning of railway logistics in the Adriatic region. By improving operational efficiency, reducing downtime, and ensuring better coordination among stakeholders, the tested ICT solutions support a modal shift toward rail and contribute to more sustainable transport patterns in line with EU goals. The improved alignment between rail processes, terminal operations, and port activities also enhances the regional logistics ecosystem, making it more resilient and responsive to both market and policy pressures.

7. Macroregional (EUSAIR) Impacts

At the macroregional level, the CROSSFREIGHT pilots support the broader objectives of the EU Strategy for the Adriatic–Ionian Region (EUSAIR), particularly within its focus on connectivity, sustainable transport, and cross-border cooperation. By demonstrating the feasibility and added value of digitalisation in diverse railway and port environments, the project contributes to building a more cohesive and interoperable logistics system across the Adriatic macroregion. The fact that the pilots were implemented in both Italy and Croatia, involving nodes of varying capacities and operational models, highlights their potential to strengthen cross-border alignment and support the gradual harmonisation of operational standards.

Digital tools tested through the project enhance the macroregion's ability to address shared challenges such as limited interoperability, fragmented communication channels, and inefficiencies in last-mile rail processes. Improvements in data quality, monitoring capabilities, and operational planning reinforce the macroregion's overall transport performance and contribute to a more competitive multimodal corridor. The increased reliability and predictability of rail services support EUSAIR goals of improving regional connectivity, reducing environmental impacts, and promoting sustainable mobility across borders.

Moreover, the collaborative nature of the CROSSFREIGHT pilots demonstrates the importance of knowledge exchange and coordinated innovation across the macroregion. Partners engaged in mutual learning, shared methodologies, and aligned testing

approaches, creating foundations for longer-term cooperation beyond the project. This collaborative spirit is essential for the macroregional agenda, which emphasises joint problem-solving, shared strategies, and coordinated development pathways. By producing practical digital solutions that can be adopted by other Adriatic–Ionian nodes, the project contributes directly to the strengthening of macroregional governance, capacity building, and policy alignment.

In summary, the CROSSFREIGHT FOTs showcase how targeted digital interventions at local and regional levels can collectively support a more integrated, efficient, and sustainable macroregional transport system. Their impacts reinforce EUSAIR objectives and contribute to the long-term ambition of transforming the Adriatic–Ionian Region into a well-connected, interoperable, and climate-resilient logistics corridor.

8. EU Policy Impacts

The impacts generated by the CROSSFREIGHT Field Operational Tests extend beyond local and regional levels and contribute meaningfully to several key EU transport, digitalisation and sustainability agendas. The improvements achieved in operational efficiency, data reliability and multimodal integration directly reinforce the objectives set out in EU strategies aimed at strengthening rail freight, modernising port operations and supporting the gradual decarbonisation of transport systems. By enhancing the performance of last-mile rail processes and improving coordination between infrastructure managers, railway undertakings, port authorities and terminal operators, the pilots support the broader EU ambition to increase the competitiveness of rail in comparison to road transport. This aligns closely with the goals of the Trans-European

Transport Network (TEN-T), which emphasises seamless multimodal connections, smarter port-rail interfaces and the strengthening of core and comprehensive corridor performance across Member States. CROSSFREIGHT pilots, particularly those implemented in major TEN-T ports such as Ravenna, Trieste, Venice and Rijeka, demonstrated how targeted digital interventions can improve the operational reliability and capacity of nodes that serve as strategic gateways to the wider European freight system.

In addition, the project contributes to the implementation of the EU's digitalisation priorities within the transport sector. Tools developed through the pilots, ranging from advanced optimisation engines to IoT-based monitoring platforms and digital safety-reporting systems, reflect the EU's wider push towards data-driven mobility and interoperable digital ecosystems. The improvements in data quality, transparency and real-time availability are consistent with the objectives of the EU Digital Strategy, which seeks to promote the adoption of digital tools that enhance efficiency, safety and user experience across all transport modes. By demonstrating how digital systems can replace paper-based workflows and fragmented communication channels, the pilots also support the implementation of regulatory instruments such as TAF-TSI, which require harmonised and structured data exchange across the European rail network.

At the environmental level, the CROSSFREIGHT pilots reinforce the goals of the European Green Deal and the Fit-for-55 package by creating conditions that favour a modal shift from road to rail. Enhanced planning, reduced dwell times, greater predictability and improved safety collectively make rail freight more attractive and competitive.

Optimisation tools applied in Ravenna and Trieste demonstrated the potential to reduce locomotive running hours and associated emissions, while better coordination in Rijeka and more reliable monitoring in Sangritana and Venice also contribute indirectly to reducing unnecessary movements, delays and fuel consumption. These benefits illustrate how digitalisation can support the EU's transition to a climate-neutral transport system.

The project also contributes to stronger compliance with EU safety requirements. The AIN digital case-management platform, for example, strengthens alignment with the Railway Safety Directive (EU 2016/798), ensuring that accident and incident data are captured, stored and analysed in a structured and transparent manner. This supports national safety oversight framework and indirectly enhances cross-border safety harmonisation. Similarly, the monitoring of critical infrastructure components in Venice and real-time surveillance in Sangritana contribute to the EU's broader emphasis on risk reduction and infrastructure resilience.

Finally, CROSSFREIGHT strengthens the EU's long-term vision of a more integrated, cooperative and resilient transport space. By demonstrating the effectiveness of digitalisation across different contexts and operational environments, the project contributes to policy discussions about future investments, digital standards and cross-border transport governance. It validates the role of EU cohesion and Interreg programmes in fostering innovation and capacity building among ports and terminals of varying sizes. The evidence gathered through these pilots shows that targeted, scalable and cost-effective digital solutions can generate tangible policy-relevant outcomes,

supporting a more harmonised, interoperable and future-ready European freight ecosystem

9. Cross-node Impact Comparison

Impact Area	Highest Demonstrated Impact	Key Examples
Usability	Šibenik, AIN	simple UI; structured workflows
Automation	Ravenna, Trieste	algorithmic planning; PCS integration
Safety	AIN, Sangritana, ERF	digital investigations; monitoring; predictive maintenance
Market Competitiveness	Rijeka, Trieste	real-time visibility
Infrastructure Optimisation	Ravenna, ERF	yard management optimisation
Scalability	All nodes	high transferability documented

10. Conclusions

The results of the Field Operational Tests implemented within the CROSSFREIGHT project clearly demonstrate that digitalisation, regardless of the technological level applied, brings substantial and measurable improvements to rail–port operations across the Adriatic region. The pilots confirmed that both advanced ICT systems and simpler, low-cost tools

can significantly enhance efficiency, safety, and the overall quality of decision-making within multimodal logistics chains. Throughout all pilot nodes, operators reported clearer workflows, greater transparency and reliability of data, and improved coordination mechanisms—even in settings that had previously relied heavily on manual procedures. Digital tools consistently reduced operational uncertainties, improved the accuracy of shared information, and contributed to a more structured and predictable working environment.

A particularly relevant finding is the strong enhancement of situational awareness achieved through real-time monitoring, live data visualisation, and automated information flows. Nodes equipped with optimisation engines or real-time monitoring platforms experienced more reliable planning, faster responses to operational events, and a notable reduction in duplicated communication. In parallel, soft tools such as those deployed in Šibenik and the AIN investigation system demonstrated that significant qualitative improvements can be achieved even without large technological investments. These solutions strengthened internal workflows, facilitated communication between different actors, reduced the risk of errors, and provided a low-barrier entry point to digital transformation for nodes with limited ICT capacity.

The pilots also delivered important safety and infrastructure-related benefits. Solutions such as Sangritana's monitoring and surveillance system and ERF's condition-monitoring platform support safer operations through early detection of anomalies, predictive maintenance, and reduced exposure to manual error. AIN's digital platform contributes to a more robust and compliant national safety framework, enabling accurate and timely

documentation of accidents and incidents. Taken together, these innovations confirm that digitalisation significantly increases resilience and safety throughout the rail–port ecosystem.

At a broader level, the pilots demonstrated strong transferability potential. Tools developed through CROSSFREIGHT are adaptable to a wide range of operational environments, from small low-volume ports to complex TEN-T nodes. Low-cost tools can be replicated immediately in numerous regional terminals, while more advanced systems can be strategically deployed in larger freight hubs where optimisation and interoperability bring high added value. The willingness of partners to continue supporting knowledge transfer further strengthens the project's long-term impact and the potential for cross-border harmonisation.

Based on these findings, several recommendations emerge for the future development, scaling, and institutional uptake of the CROSSFREIGHT digital solutions. In the short term, priority should be given to replicating low-cost digital tools that have proven effective in enhancing basic operational coordination, procedural transparency, and data quality. These tools require virtually no infrastructural investment yet deliver measurable improvements, making them ideal for rapid deployment in small or resource-constrained environments. Strengthening data-entry procedures, standardising documentation formats, and providing structured training are also essential to ensure consistent use and data reliability, particularly in nodes with predominantly manual processes.

In the medium term, the focus should shift to expanding modular ICT platforms—such as real-time monitoring systems, freight information systems, and IoT-based tracking solutions—across terminals that demonstrate adequate digital readiness. Interoperability between these systems and existing port community platforms, rail management systems, or national infrastructure databases should be encouraged to maximise their effect. Nodes should progressively adopt shared KPI frameworks to monitor performance, identify inefficiencies, and support evidence-based decision-making. In parallel, infrastructure monitoring tools like the one tested in Porto Marghera should be introduced in other sidings and terminals to facilitate predictive maintenance and increase infrastructure availability.

In the long term, major TEN-T ports and high-capacity freight hubs should adopt advanced optimisation engines for shunting and terminal operations. These systems demonstrate strong potential to increase throughput, reduce delays, and support the decarbonisation objectives of the Green Deal by improving energy efficiency and modal shift attractiveness. To sustain these gains, digitalisation should be formally integrated into port and rail master plans, infrastructure development strategies, and regional policy frameworks. Strategic cross-border coordination should also be strengthened, ensuring that ICT architectures, data standards, and operational protocols across Italy and Croatia evolve toward a compatible and interoperable digital ecosystem.

Governance efforts will be crucial in this process. Multi-actor coordination structures, clear internal responsibilities, and transparent communication channels are essential for successful deployment and long-term operation of digital systems. Investment

mechanisms should be introduced to support digital upgrades in smaller terminals, while capacity-building programmes should ensure that human resources remain aligned with technological evolution. Aligning all digital developments with EU regulatory frameworks—including TEN-T, TAF TSI, the Railway Safety Directive, and the Green Deal—will further reinforce the strategic relevance and sustainability of the solutions.

Overall, CROSSFREIGHT has proven that the combined application of digital tools—ranging from simple operational templates to advanced optimisation engines—can transform the rail–port landscape, making it more efficient, safer, interoperable, and resilient. The lessons learned and the recommendations derived from the FOT results provide a clear pathway for future scaling, policy harmonisation, and cross-border collaboration. They collectively support the transition toward a modern, digitally enabled freight transport system capable of responding to evolving market needs, environmental objectives, and technological advancements across the Adriatic macro-region.