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CROSSFREIGHT

Deliverable 2.2.1
Field Operational Tests Report on execution



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1. Executive summary

The deliverable D.2.2.1 “Report on Field Operational Tests Execution” represents a fundamental milestone within Work Package 2 of the CROSSFREIGHT project. This document provides a comprehensive technical and operational account of the execution phase of the Field Operational Tests (FOT) conducted across the project’s 6 pilot nodes. Its primary purpose is to document and validate the ICT solutions developed to optimize rail-port integration, shunting processes, and logistics security, demonstrating the transition from the theoretical scenarios to practical, real-world applications.

The report consolidates the results of the pilot implementations, verifying how each solution was conceived, integrated, and tested against the technical and operational requirements established in the earlier stages of the project. By analyzing the feedback and data collected during the field tests, this deliverable ensures that all technical specifications and administrative milestones are fully verified.

The core findings and activities detailed in this report include:

A. Technical Validation: an assessment of the ICT development process, confirming the architectures, standards, and programming tools implemented to bridge the digital gap in the "last mile" of the railway supply chain.
B. Operational Performance: a detailed account of the testing protocols followed during the FOT phase, including the collection of system logs, performance indicators, and user feedback to measure the effectiveness of the piloted tools.
C. Organizational Accountability: verification of the roles played by internal teams and external stakeholders, ensuring that all necessary training, legal permits, and safety protocols were successfully managed to support the pilot execution.
D. Strategic Impact: a summary of key achievements and lessons learned, providing a clear roadmap for the future deployment and scaling of CROSSFREIGHT digital strategies.

In conclusion, the D.2.2.1 report demonstrates that the CROSSFREIGHT ICT strategies are operationally viable and capable of delivering measurable improvements to the Adriatic freight corridors. The evidence

gathered during this execution phase serves as the essential foundation for Work Package 3, supporting the transferability and long-term sustainability of these digital solutions across the macro-region.

1.1 Summary of individual pilots

PP1 – ITL Foundation (Port of Ravenna): Implementation of a customized and interoperable IT management system for railway shunting operations. This tool aims to transition from manual management (via email and telephone) to assisted automation to prioritize operations and optimize resource allocation.

PP2 – Adriafer (Port of Trieste): Integration and enhancement of the Sinfomar PCS as a single ICT tool for shunting requests. The solution introduces new digitized procedures between Sinfomar and the Trainshunt software to manage cancellations, request suppressions, and the sharing of a common wagon database.

PP3 – AIN: Implementation of a dedicated digital platform for reporting and analyzing railway accidents and malfunctions. The solution replaces manual management via Excel spreadsheets with integrated web-based software to improve safety and regulatory compliance.

PP4 – ERF (Port of Marghera): Introduction of a structured system for monitoring and managing railway infrastructure maintenance. This ICT solution collects data on critical components (such as switches) to adopt predictive maintenance strategies, integrating them with the existing SIMA management system.

PP6 – Sangritana (Saletti Terminal): Realization of an integrated IT solution for real-time monitoring of railway traffic over a 12 km section. The solution includes position tracking devices on trains and video surveillance cameras to ensure the security of goods stationed at the terminal.

PP7 – Port of Šibenik Authority (Port of Šibenik): Implementation of a soft ICT pilot focused on optimizing railway station capacity and loading/unloading efficiency. The solution is based on the coordination of data among stakeholders through standardized Excel templates, KPI monitoring, and operational flow

analysis to identify and mitigate bottlenecks without the introduction of new hardware or complex digital platforms.

PP8 – Transagent (Port of Rijeka): Development of a centralized digital platform that harmonizes technical and financial indicators. The system allows real-time monitoring of performance, costs, train drivers' working hours, and energy consumption, facilitating communication between departments and with customers.

2. Methodology

The methodology adopted for this report is designed to provide a rigorous and harmonized evaluation of the Field Operational Tests (FOT) executed across the CROSSFREIGHT pilot nodes. In line with the project's strategic approach, the analysis ensures that the ICT developments are not only technically functional but also fully aligned with the long-term goals of rail-port integration and corridor sustainability.

The primary data collection tool is a structured questionnaire specifically developed to capture a comprehensive technical and operational analysis of the ICT modules. Through this instrument, each partner documented the entire lifecycle of their pilot, verifying the requirements planned in the earlier stages to identify any deviations or new needs emerged during development. The questionnaire was structured into four main areas of investigation:

I. **ICT Module Development Process**: to verify if the initial requirements (data, inputs, functions) planned in WP1 and Activity 2.1 were confirmed or if new needs emerged during the coding and internal testing phases.
II. **Organizational and Administrative Activities**: to document the involvement of internal teams, the completion of training sessions, and the obtainment of necessary legal permits and safety protocols.
III. **Procedural Execution (execution phase)**: to describe the actual operational protocols followed during the tests, including the test environment (real or virtual) and the roles of the staff involved.

IV. **Evaluation and Consolidation**: to measure success through technical performance indicators and collect "lessons learned" for future scalability.

The evaluation follows a mixed-method approach that combines quantitative data—such as system logs, TAF TSI standards, and technical performance indicators—with qualitative feedback from operators. This consolidation process allows for a direct comparison between the achieved results and the “TO BE” scenarios defined at the project's outset, ensuring that the pilot actions contribute effectively to the program’s outputs. Finally, the methodology integrates the pilot video documentation as a visual proof-of-concept, providing a roadmap for the future scaling of these digital solutions across the Adriatic macro-region.

Sustainability-oriented multidimensional evaluation approach

During the execution of the Field Operational Tests, the evaluation methodology was further developed in order to address an important aspect emerging from the practical implementation of the pilot actions. While the original assessment framework was primarily focused on technical performance, operational effectiveness and compliance with the “TO BE” scenarios defined in the previous project activities, the execution phase demonstrated that the strategic value of a digital solution cannot be assessed exclusively through technical indicators.

In particular, the Adriafer pilot highlighted the opportunity to complement conventional technical and operational KPIs with a broader set of decision-support criteria capable of assessing the economic, environmental, social and governance implications associated with the deployment and future scaling of digital rail-port solutions.

For this purpose, a sustainability-oriented multidimensional evaluation framework was introduced. The framework does not constitute a formal sustainability reporting exercise and does not imply the application of mandatory corporate sustainability reporting requirements. Rather, it incorporates selected evaluation principles commonly used in ESG management and sustainability reporting processes in order to provide a more comprehensive evidence base for strategic decision-making and future exploitation.

The framework extends the conventional assessment of technical feasibility through five complementary dimensions.

Environmental and climate performance considers the extent to which improved information flows, process optimisation and reduced operational inefficiencies may contribute to lower energy consumption, reduced greenhouse gas emissions and, more generally, the decarbonisation pathway of rail-port logistics operations. Particular attention is given to the methodological connection between operational performance indicators and potential GHG-related impacts.

Economic sustainability and cost-effectiveness assess whether the benefits generated by digitalisation — including reduced processing time, fewer duplicated activities, improved allocation of operational resources, lower error rates and reduced dependence on fragmented manual communications — can support a sustainable business and investment case for further deployment.

Resource efficiency and Do No Significant Harm-oriented considerations examine whether the implementation and scaling of the solution generate unintended adverse environmental or operational effects and whether digitalisation contributes to a more efficient use of energy, infrastructure, information and organisational resources.

Human-centric and non-discriminatory digitalisation considers the interaction between operators and digital systems, including usability, accessibility, transparency of automated processes, maintenance of adequate human oversight and the avoidance of discriminatory or unnecessarily exclusionary effects arising from human-machine interaction. The objective is to ensure that technological efficiency is accompanied by safe and inclusive organisational adoption.

Governance and accountability address data quality, ownership and traceability, responsibilities for information management, interoperability governance, cybersecurity and access control, stakeholder accountability and the capacity to monitor the performance of the solution over time through structured and auditable KPIs.

The introduction of these dimensions represents a methodological enhancement of the CROSSFREIGHT pilot evaluation process. It enables technical evidence generated through the FOT to be connected with

the wider strategic questions associated with scalability, transferability, investment prioritisation and long-term sustainability. The approach therefore also creates a direct methodological bridge between the validation activities carried out under WP2 and the exploitation and transferability activities developed under WP3.

a. Survey Introduction

The primary objective of this section is to provide a comprehensive overview of the data collection process established to validate the Field Operational Tests (FOT) within Work Package 2. This analysis serves as the formal bridge between the digital solutions designed in the earlier stages of the CROSSFREIGHT project and their actual deployment in real-world railway and port environments.

The survey was conceived to ensure that each of the seven pilot actions maintains a high degree of consistency with the technical requirements and strategic goals defined in Activity 2.1. By systematically documenting the evolution of each ICT module, the introduction of this survey allows for a transparent verification of technical integrity, organizational accountability, and operational effectiveness. Ultimately, the information gathered here provides the evidentiary basis for assessing the success of the pilots and their contribution to the overall enhancement of the Adriatic freight corridors.

b. Survey Methods

To ensure a harmonized evaluation across diverse technological solutions, the project adopted a standardized reporting methodology. The process was centered on a structured digital questionnaire distributed to the Project Managers of the partners responsible for the seven pilot nodes. This instrument was specifically designed to capture technical specifications, such as programming languages and compliance with TAF TSI standards, alongside administrative milestones and operational protocols.

The methodology followed a phased approach: initially, partners provided a detailed account of the ICT development and internal testing phases; subsequently, they documented the field execution, including system logs, Key Performance Indicators (KPIs), and qualitative feedback from operators. To ensure the reliability of the report, all submissions underwent a central review process to verify consistency and address any technical deviations. Finally, this data was integrated with a requirement for video

documentation, providing a visual proof-of-concept that complements the technical findings and supports the future transferability of the piloted solutions.

c. Questions

The questionnaire was structured into four thematic blocks, meticulously designed to extract technical evidence and operational insights from each pilot node. This modular approach ensured that the data collected was not only comprehensive but also directly comparable across different technological solutions. The logic behind the questions is detailed below:

I. **ICT Module Development Process**: the questions in this section were aimed at validating the technical transition from design to product. Partners were asked to describe their software architectures, the programming languages used, and how they integrated standards like TAF TSI. The objective was to verify if the initial technical requirements were met or if real-world coding challenges led to justified deviations from the original plan.

II. **Organizational and Administrative Activities**: this block investigated the "readiness" of the organization. Questions focused on the human and legal factors necessary for the pilot's success, such as the involvement of internal technical teams, the delivery of specialized training for staff, and the procurement of specific legal permits or service level agreements (SLAs) required to operate in railway and port environments.

III. **Procedural Execution (FOT Phase)**: this is the operational core of the survey. The questions required a detailed account of the testing protocols, including the specific environment (real, virtual, or hybrid) and the timing of the tests. Partners had to document the roles of the personnel involved and the types of data collected, ranging from automated system logs to qualitative operator feedback, to ensure a full picture of the tool's performance in the field.

IV. **Evaluation and Consolidation**: the final set of questions aimed at strategic assessment. Partners were asked to define their success criteria and report on specific Key Performance Indicators (KPIs). Furthermore, this section encouraged the identification of "lessons learned" and key

achievements, providing the project with critical recommendations for the future scalability and transferability of these ICT tools to other corridors in the Adriatic macro-region.

This structured set of questions was essential to transform raw operational data into a technical evidence base, ensuring that every result reported in this deliverable is supported by a clear and verifiable methodology.

NB - **Video Documentation**: the survey included a request for visual evidence to complement the technical data. Acknowledging current time constraints, partners not yet able to provide footage have submitted a proposed production plan. This ensures that while the current report focuses on technical validation, the visual proof-of-concept will be finalized in the coming months, maintaining full transparency with the JS regarding the project's operational timeline.

3. Crossfreight field operational tests execution

The execution of the Field Operational Tests (FOT) represents the practical implementation of the digital strategies developed within the CROSSFREIGHT project. This phase marks the transition from the theoretical “TO BE” scenarios and technical architectures to the operational testing of ICT solutions in real-world railway and port environments. The primary goal of these tests was to validate the effectiveness of the new tools in optimizing shunting operations, improving infrastructure maintenance, and enhancing the overall security and efficiency of freight corridors.

The following sections provide a detailed account of the activities performed by each pilot node. Based on the data collected through technical questionnaires, the report analyzes the development process, the organizational readiness, and the operational results achieved during the testing period.

Although the pilot actions involve different technological applications, ranging from IoT-based monitoring to automated shunting management, they all share a common objective: bridging the digital gap in the “last mile” of the logistics chain. This chapter documents the technical successes, the challenges

encountered, and the performance indicators that confirm the viability of the CROSSFREIGHT solutions for future large-scale adoption.

I. ICT module development process: analysis; technical development; technical specifications

PP1 Fondazione ITL – Port of Ravenna

ANALYSIS: The solution was conceived and developed based on the requirements defined in Activity 2.1. The main requirements regarding data, input, and functionality were confirmed during the development phase, demonstrating the accuracy and completeness of the initial planning. During development, small adjustments or refinements were assessed and applied as needed to ensure correct system operation and adherence to the originally defined project objectives. Overall, the final solution is consistent with the planned requirements, ensuring reliability, robustness, and compliance with the initial specifications.

TECHNICAL DEVELOPMENT: The development of the module followed the approach defined in Activity 2.1, adopting a structured and iterative process covering all main phases, from development to testing and integration. The work included the implementation of core functionalities and business logic, including the optimization and assignment components, followed by internal testing to verify functional correctness and data handling. Subsequently, tests were carried out in a protected environment to validate system behavior under realistic conditions. Integration activities were conducted progressively, ensuring alignment with existing systems and platforms and maintaining consistent management of data and operational flows. Overall, the development process remained consistent with the initial plan, with incremental improvements introduced to ensure robustness, reliability, and effective integration with existing systems.

TECHNICAL SPECIFICATIONS: The technologies, standards, and architectural choices defined during Activity 2.1 were largely maintained throughout the implementation phase. The selected programming languages, tools, and system architecture proved suitable to meet the functional and performance requirements. Compliance with relevant standards (e.g. TAF TSI) was also preserved, ensuring



interoperability. Some minor adjustments were introduced to improve performance, scalability, and integration with external systems, without altering the overall architectural approach. In particular, refinements were made to the assignment logic in order to improve the consistency between inbound and outbound trains and enhance the reliability of the optimization results. In addition, targeted front-end adjustments were implemented to improve usability and to better support planning operations and data validation. Overall, the final solution remains aligned with the initial design, with incremental improvements to ensure robustness, performance, and interoperability.

PP2 Adriafer – Port of Trieste

ANALYSYS – TECHNICAL DEVELOPMENT – TECHNICAL SPECIFICATIONS:

The development process was designed to evolve the existing digital ecosystem of the Port of Trieste, specifically focusing on the interoperability between the **PCS Sinfomar** and the shunting management software **Trainshunt**. Following the requirements identified in Activity 2.1, the technical development was structured into three main modules:

1. **Digital Shunting Suppression:** Implementation of a web-service-based protocol to allow the digital cancellation of shunting requests, ensuring real-time synchronization and eliminating manual "out-of-band" communications (e.g., emails/phone calls).
2. **GTR-GCSP Interoperability:** Technical integration between "Train Management" and "Circulation" modules to automate the flow of train composition data, ensuring that the information used for shunting reflects the actual status of the train.
3. **Unified Wagon Master Data:** Development of a centralized database within Sinfomar to store and share technical wagon specifications (tare, length, IDs), acting as the "Single Source of Truth" for all involved ICT tools.

- **Architectures & Standards:** The modules utilize REST/SOAP web services and standard logistics data formats to ensure compatibility across different platforms.

- **Challenges:** The primary challenge involved harmonizing data update frequencies between the terminal-side operations and the rail-side shunting execution to prevent data latency.

PP3 AIN

ANALYSIS: The solution was developed around a clearly defined workflow that supports all key stages of the accident investigation process, including accident notification, on-site investigation documentation, tracking investigation status (open/closed), and managing safety recommendations. To enhance analytical capabilities, the system incorporates advanced filtering options and data-visualization tools that enable users to identify high-risk areas, recurring causal factors, and performance gaps. At present, accident investigations are managed through Excel spreadsheets and manual communication channels. The new platform introduces secure login access, structured digital workflows, and user-friendly interfaces, enabling full digitalization of the process.

TECHNICAL DEVELOPMENT: The development of the application and its modules followed the plan defined in Activity/Deliverable 2.1, with the implementation structured into several key phases: architectural design, coding, internal testing, testing in a protected environment, and final validation. All core modules—Notifications, Serious Accidents/Accidents/Incidents, On-Site Investigations, Suicides and Attempts, Investigations, and Safety Recommendations—were developed according to the functional requirements. Each module includes structured data entry, document upload capabilities, advanced filtering, data export, and graphical/statistical visualization features. The application was built using modular architecture, enabling individual modules to be activated or deactivated depending on the deployment environment. User administration was implemented in line with the requirements, including user registration, authentication, session management, role-based access control, user groups, and audit logging. The system supports simultaneous use by an unlimited number of users and provides responsive design across devices. During development, the requirements defined in Deliverable 2.1 were confirmed as valid. Additional needs emerged primarily in the areas of enhanced usability, more advanced filtering options, and optimization of the data-import process. A dedicated mechanism was implemented to

support the migration of existing data from Excel (.xlsx) files for the years 2022–2025, covering notifications, accidents, incidents, investigations, and related datasets. This ensured smooth integration with existing operational records. No major deviations from the planned timeline occurred. Minor adjustments were made to accommodate extended validation of imported datasets and to ensure consistent behavior of the responsive interface across different browsers and devices.

TECHNICAL SPECIFICATIONS: The technologies, standards, and architectural principles defined in Activity/Deliverable 2.1 were maintained throughout implementation. The application was developed as a web-based solution accessible through standard browsers, with confirmed compatibility with the latest versions of Google Chrome, Microsoft Edge, and Mozilla Firefox. The modular architecture supports future expansion and integration of additional components. The system includes full support for user authentication, session security, role-based access control, audit logging, and document management. It enables data import from external systems (CSV, Excel) and export in standard formats. All modules support document uploads (PDF, Word, JPG, PNG, EML) and provide advanced filtering and reporting capabilities. The application is compatible with the required operating systems and environments, including Windows Server 2022/2025, Ubuntu 24.04 LTS, Debian 11, and Oracle Linux 8/9. Secure communication is ensured through the implementation of SSL/TLS certificates for HTTPS. No significant changes to the initially selected technologies or standards were required, and no technical limitations necessitated deviations from the planned architecture. Unforeseen challenges primarily related to the harmonization of historical data formats and ensuring consistent mapping of legacy Excel datasets into the new structured database model. These issues were resolved through additional validation rules, automated data-quality checks, and iterative testing of the import process.

PP4 ERF – Port of Marghera

ANALYSIS: The Minosse ICT tool was born from the need to monitor the condition of the sidings railway infrastructure, allowing, once the process is digitized, the ability to obtain a representative sample of related data. The next phase will be to optimize the maintenance process and improve the safety of

shunting operations. The provisions of Activity 2.1 have been implemented. It was not necessary to revise the previous analysis or add any additional features.

TECHNICAL DEVELOPMENT: The most challenging task was analyzing the technical requirements the software needed to meet to comply with the current regulatory framework. Once the regulatory framework was identified, we proceeded to analyze the process of field data collection, data analysis, and data storage. The goal of having a defined and consistent data structure will allow for specific analyses in the future that will help determine a better maintenance policy and further improve the safety of railway operations. There were no significant deviations from the activities planned in previous activities.

TECHNICAL SPECIFICATIONS: The use of the technologies identified in Activity 2.1 is confirmed, as are the reference standards on the basis of which the ICT tool was developed. Great importance was also given to the tool's usability when used in the field.

PP6 Sangritana – Terminal Saletti

ANALYSIS: The solution was developed in line with the requirements planned in activity 2.1. It was confirmed that the input would come both from the tracking devices and from the manual input of the operators. The confirmed functions were both on safety and security, improving the operational aspects of the rail compound and the overall productivity.

TECHNICAL DEVELOPMENT: In terms of development, the only difference from the plan in activity 2.1 was related to the timetable of the action. The delays in the planned timeline were only related to the actual change of the management structure of Sangritana following the privatization of the company in January 2026. This happening has slowed down the procurement operations, which were finalized on the 10th of March 2026, and allowed the final beginning of the construction stage. Given that, apart from the delays in the timeline, the phases were all respected. The main development phase included the drafting of the software system with the software house, as well as drafting how the software platform would have matched the hardware interaction.

Once agreed with the external developer the main software/hardware architecture, it began the phase of coding, that was followed by a close contact with the internal project team of Sangritana. The integration of the existing system was not overseen, as there is no PCS in place at the moment in the compound, and the eventual interaction with the RFI PCS system will be included in the roadmap part.

TECHNICAL SPECIFICATIONS: The initial architecture in Activity 2.1 was not entirely specified in detail, leaving more freedom to the next step for the implementation. It was respected the main criteria, which is connected to the gateway process. The current architecture of the system is the following:

- It is a web-based solution, implementing a Virtual Gate for wagons and trains passage detection;
- It uses a microservice architecture, integrating active tags and WiFi antenna as gateway via Azitek to track the movement and presence of trains and wagons;
- The core deliverable included high-performance REST APIs, a modern, server-side rendered (SSR) web application;
- The core technologies used are Java21/Spring Boot 3.x for the core development framework, with modular microservices, Spring Data JPA as data persistence layer, Postgre SQL with Flyway as a primary relational database, MapStruct as high-performance and type-safe DTO-Entity Mapping, and Azitek Integration as beacon/gateway tracking system.

PP7 Port Authority of Sibenik – Port of Sibenik

ANALYSIS: The solution was conceived as a low-cost, soft ICT pilot focused on optimizing railway station capacity and loading/unloading efficiency at the Port of Šibenik. The concept was based on the optimization of existing infrastructure without introducing new hardware or complex digital platforms. The requirements defined in Activity 2.1 were confirmed during development:

- Manual data input (train arrivals/departures, wagon numbers, loading times)
- Standardized Excel templates
- KPI monitoring (throughput, loading time, error rate, stakeholder satisfaction)
- Basic analytics (formulas, pivot tables, charts)

- Shared data coordination among stakeholders

  During development, additional needs emerged:

- Clearer data-entry guidelines to prevent inconsistencies
- Standardization of naming conventions for trains and containers
- More structured weekly validation procedures
- Backup protocol definition to avoid data loss

No major functional deviations occurred, but stronger emphasis was placed on data validation and coordination procedures.

TECHNICAL DEVELOPMENT: The module was developed in the following phases:

1. Design Phase

- Creation of Excel structure (separate sheets/modules)
- Definition of KPIs and calculation formulas
- Development of templates for train schedules and feedback forms

2. Internal Testing

- Testing of formulas and pivot tables
- Simulation of daily data entry
- Verification of KPI calculation logic

3. Protected Environment Testing

- Testing on a single railway platform
- Limited number of daily trains
- Controlled 2-month testing period

Integration with existing systems: The solution was not directly integrated with a PCS or external automated systems. Instead, it relied on manual data transfer from existing port reports and railway operator systems into standardized Excel templates. Files were shared via local server or OneDrive.

Timeline deviations: No major delays occurred. Minor adjustments were made to improve template usability and validation processes. Development remained aligned with the Activity 2.1 plan.

TECHNICAL SPECIFICATIONS: Technologies and tools used:

- Microsoft Excel (.xls/.csv environment)
- Pivot tables, formulas, filters, conditional formatting
- Charts (bar charts, line charts, Gantt chart visualization)
- Local server / OneDrive for file sharing

Architecture:

- Centralized shared Excel environment
- Manual data input by stakeholders
- Weekly validation review process

No programming languages or advanced architectures were introduced, as the soft pilot was intentionally designed as a low-complexity solution.

No deviation from the planned architecture occurred.

Unforeseen technical challenges:

- Risk of inconsistent manual data entry
- Risk of version conflicts in shared files

Mitigation measures:

- Standardized templates
- Data-entry guidelines
- Weekly review meetings
- Frequent file backups

PP8 Transagent – Port of Rjieka

ANALYSIS: The solution was developed within the CROSSFREIGHT pilot project to improve digitalization and operational efficiency in railway freight transport. The main objective was to develop a Freight Information System (FIS) capable of monitoring train operations in real time and linking technical and financial indicators. Most requirements defined in Activity 2.1 were confirmed during development,

including real-time train monitoring, documentation management, personnel management, and automated notifications. During development, additional needs appeared related to system interoperability and improved communication between railway operators, infrastructure managers, and terminal operators.

TECHNICAL DEVELOPMENT: The development process consisted of several phases: preparation of technical specifications, software development, internal testing, and operational testing.

The system modules were first tested in a controlled environment and later integrated with existing operational systems. Field Operational Testing (FOT) was then conducted under real operational conditions to validate system performance, real-time monitoring, and communication functions. Only minor adjustments were made during development to improve system integration.

TECHNICAL SPECIFICATIONS: The system was developed as a web-based platform accessible from desktop computers, laptops, tablets, and mobile devices. It includes modules for train monitoring, personnel management, document management, and automated notifications.

The technologies initially planned were maintained, including database solutions and secure authentication mechanisms with role-based user access. Some interoperability challenges were encountered during development but were resolved through additional system interfaces and integration improvements.

II. Organizational and administrative activities: roles, responsibilities, and internal organization; stakeholder and authority involvement; legal permits, service agreements, and safety protocols

PP1 Fondazione ITL – Port of Ravenna

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: In developing the tool, ITL is relying on an external expert, Circle Group, experienced in the field and already engaged in developing the Rail

Management Platform for the Port of Ravenna Authority. This ensures both operational and conceptual continuity of the tool with the rest of the system used. The tasks are divided as follows between organizations and their internal teams:

- ITL Foundation is responsible for the overall management of pilot action. The team consists of:
  - Margit Kuuse – project manager
  - Francesco Nanni Costa – project manager of the pilot action
  - Francesco Magagnoli – supporting team member
- Circle Group is responsible for the actual development of the software module, its testing, user manual and training. Their team consists of:
  - Matteo Nicoli – project manager
  - Costanza Chiesa – product manager
  - Greta Novelli – optimization specialist
- The Port of Ravenna Authority is engaged as the testing site of the tool and their representative is: Andrea Minardi – Smart Port and Security Manager

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The only authority responsible for the oversight is the Port of Ravenna Authority which is the site of the pilot action. No approvals were necessary, whereas all the interactions regarding the pilot are held regularly and the authority is constantly updated on the project's progress. The main stakeholders involved are the two shunting operators – MIST and Dinazzano Po who were consulted both in the initial phase of the pilot action and during the testing of the user interface. The testing with shunting operators suffered a slight delay as it was difficult to schedule. To mitigate the risk of discovering any issues too late in the project timeline and not being able to take timely action, meanwhile a preliminary testing session was carried out with the Port Authority on the 17th of February. On the 3rd of March, a meeting was held with a wider circle of stakeholders to discuss matters related to the Rail Management System. On this occasion, the software module developed in the pilot action was presented to the terminal operators and the customs office. This allowed to gather some useful insights and feedback.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? Were additional administrative steps required during execution? No legal permits were necessary. However, since the software module belongs to ITL, an agreement will need to be signed with the Port of Ravenna Authority for its use after the end of the project.

PP2 Adriafer – Port of Trieste

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: Adriafer S.r.l., led by CEO Maurizio Cociancich, acted as the Work Package Leader and pilot coordinator. Technical Implementation: Info.era S.r.l. (Circle Group) managed the software development and system integration, with Andrea Rusich as the technical lead. Operational Validation: Adriafer's rail planners and ground staff were designated as Key Users for the testing and validation phases.

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The implementation required close coordination with the Eastern Adriatic Sea Port Authority (AdSPMAO) for the evolution of the Sinfomar PCS. The developments regarded the integration between the Adriafer IT platform Trainshunt and the PCS Sinfomar owned by AdSPMAO in order to enable the Golive of the digitalisation of the shunting operations management within the Trieste port. Furthermore, the operational flows were validated in consultation with Terminal Operators (e.g., Trieste Marine Terminal, Samer Seaports & Terminals), AdSPMAO and Adriafer to ensure the outputs met the needs of the entire logistic chain.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? Were additional administrative steps required during execution? The development strictly adhered to the Safety Certificate EU-1020240132. Service Level Agreements (SLAs) regarding data sharing and system uptime were aligned with the existing port regulations and the safety protocols required for shunting operations in a high-density maritime-rail node.

PP3 AIN

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: The supplier provided structured user training covering the use and operation of the application. The training lasted six hours and ensured that end users understand how to work with all relevant modules, manage data entry, perform searches and filtering, upload documents, generate reports, and use administrative features where applicable. This training is part of the procurement scope, and it was done.

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The involvement of external stakeholders will take place solely in the event that the Agency determines their participation to be necessary.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? All legal permits, service agreements, and safety protocols identified in Activity/Deliverable 2.1 were successfully obtained during project execution. This included compliance with data-protection requirements, secure-access protocols, and operational safety standards relevant to the handling of accident and investigation data. A small number of additional administrative steps were required, primarily related to the validation of data-security measures and confirmation of SSL/TLS certificate installation for HTTPS communication. These steps did not impact the overall timeline and were addressed through coordinated actions between the supplier and the Contracting Authority. No significant legal or procedural obstacles were encountered, and all issues were mitigated through timely communication and documentation updates.

PP4 ERF – Port of Marghera

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: The company selected to develop the project, as well as its internal organization, allowed the ICT tool to be implemented on time and according to the expected methods. In particular, the internal organization, identified in the preliminary phase based on the specific skills of each operator, allowed for an in-depth analysis of the regulatory, technical, and operational aspects.

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The North Adriatic Sea Port Authority System, as the owner of both the railway infrastructure and the software for which Minosse will be an extension, has been involved since the project's preliminary phase. The Minosse project will not only streamline the maintenance process and improve the railway operational safety, but will also reduce maintenance costs while ensuring maximum efficiency. This cost reduction will have a positive impact on all port operators in terms of shunting service costs.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? No issues were encountered with obtaining legal permits, as identified in Activity 2.1, and no additional administrative procedures were required during execution.

PP6 Sangritana – Terminal Saletti

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: The internal organization was the following: Marco Grifone was the project manager responsible for the overall organization of the testing phase and for the pilot action; Sandro Imbastaro was the supervisor for the internal activities of Sangritana, including the permissions, the adaptations of the system to the current operational usage of the platform; Luigi Di Cicco was the operational supervisor, checking the activities within the pilot action to be in line with the current management of the rail compound; Gianni Moretti was the technical consultant within the organisation to check the validity of the solution in terms of safety and security. In terms of training sessions, the training sessions will be held with delays, approx. in the month of May 2026, due to the previously mentioned delays in the pilot procurement.

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The main external stakeholders were related to the trains that are currently performed in the rail compound of Saletti. The trains undertakers have confirmed the usage of the pilot devices on board of their trains. No authorities interactions were needed for the competition of the pilot action.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? The only permits needed in Activity 2.1 were internal and related to the safety measures within the Saletti-Atessa-Fossacesia rail compound. These permits were successfully obtained.

PP7 Port Authority of Sibenik – Port of Sibenik

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION:

Port Authority (LUŠ):

- Overall coordination
- Infrastructure data (platform availability, arrival/departure times)
- KPI monitoring

Railway Operators:

- Train IDs and schedules
- Wagon/container numbers

Cargo Owners:

- Feedback on loading accuracy and delays

Planned testing teams were involved as foreseen.

Training sessions:

- Short internal workshops (Excel template usage)
- Practical demonstrations of data entry
- Explanation of KPI calculations and reporting structure

Outcomes:

- Improved understanding of standardized reporting
- Reduction of initial data-entry errors

STAKEHOLDER AND AUTHORITY INVOLVEMENT: External stakeholders involved:

- Railway operators
- Cargo owners

- Port operational staff

No additional external authority approvals were required since:

- No infrastructure modification occurred
- No safety-critical system was altered
- No integration with national railway IT systems was implemented

Stakeholder coordination functioned as planned, with minor initial adjustments in data submission timing. No major delays were recorded.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? Since the pilot:

- Used existing infrastructure
- Did not introduce new operational risk
- Did not modify signaling or safety systems

No additional legal permits were required. Existing service agreements between Port Authority and railway operators remained valid. No additional administrative steps were necessary.

PP8 Transagent – Port of Rjieka

ROLES, RESPONSIBILITIES, AND INTERNAL ORGANIZATION: Transagent Rail Ltd. acted as the pilot coordinator and provided operational expertise and testing support. The technology partner was responsible for system development and implementation. Operational staff, including train drivers and dispatchers, participated in testing activities. Training sessions were conducted before the Field Operational Testing phase to ensure that users were familiar with system functionalities and operational procedures.

STAKEHOLDER AND AUTHORITY INVOLVEMENT: The pilot involved several external stakeholders including the infrastructure manager (HŽ Infrastruktura), terminal operators (AGCT Rijeka), and other railway operators. Stakeholders contributed to operational coordination, data exchange, and validation

of testing procedures. The required operational interactions and approvals were obtained through existing operational frameworks.

Were the legal permits, service agreements, and safety protocols identified in Activity / Deliverable 2.1 successfully obtained? All pilot activities were carried out in accordance with national and European railway regulations and safety requirements. Transagent Rail operates under a valid Single Safety Certificate. Existing operational agreements with infrastructure managers and terminal operators enabled pilot testing without additional legal permits. Safety protocols and operational procedures were respected throughout the testing phase.

III. Procedural activities (execution phase): operational protocol for field operational testing; data and feedback collection

PP1 Fondazione ITL – Port of Ravenna

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: During the Field Operation Testing (FOT), functional tests were performed to verify the correct behavior of the system across the main operation workflow, from user access to the consultation of optimization results. The testing activities were divided into the following macro-phases:

1. System Access: Access to the system was verified using both valid and invalid credentials.
2. Navigation and Operational Management: the main application sections were accessed and the core functionalities for data search and visualization were tested.
3. Train Selection and Planning: train selection (single and multiple) and the overall planning process were validated, including the association of inbound and outbound trains and terminal assignment.
4. Request submission: the submission of optimization requests was tested with both incomplete and complete data sets.

5. Monitoring of Requests: the system functionalities for viewing input and output data were verified, including request history and result details.
6. Consistency Checks: checks were performed to ensure consistency between input and output data, completeness of results, and correct temporal sequencing, including the handling of unserved trains.

DATA AND FEEDBACK COLLECTION: During the Field Operational Testing (FOT), the collected data focused on two main aspects: Key Performance Indicators (KPIs) and user feedback. KPIs were automatically calculated in the backend, providing objective information on system performance and process correctness. At the same time, user feedback was gathered through operational test sessions, during which operators provided observations on functionalities, usability, and the effectiveness of operational procedures. This combination of system data and direct user input allowed a comprehensive evaluation of system performance and helped identify potential areas for improvement.

PP2 Adriafer – Port of Trieste

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: The FOT followed a structured protocol aligned with the FESTA methodology described in D.2.1:

1. Pre-Test Phase: Technical validation of the new modules in a controlled "sandbox" environment.
2. Pilot Execution: Real-world testing conducted at the Trieste port yards, specifically monitoring the digital authorization cycle for shunting maneuvers.
3. Monitoring: Verification of the "Single Source of Truth" principle during active operations.

DATA AND FEEDBACK COLLECTION:

- Data Types: System logs (to verify data integrity and transmission speed), error rate tracking (to measure the reduction in manual entry mistakes), and KPI monitoring (e.g., reduction in process execution timing).
- Feedback: Qualitative data was collected through debriefing sessions with operators to assess the impact of the new interface on their daily workflow.

- Constraints: Access restrictions to certain sensitive operational data were managed through anonymization within the test environment.

In addition to the technical and operational data collected during the field test phase (FOT), the assessment was supplemented by information relevant to evaluating the cost-benefit ratio, resource efficiency and environmental implications of the pilot project. The analysis examined how the digitisation and integration of information flows relating to marshalling operations could help to reduce process execution times, manual tasks, duplicate information exchanges and the inefficient use of operational resources.

The assessment also considered energy and environmental performance indicators associated with Adriafer's operational activities, with a view to establishing a methodological link between improvements in operational efficiency and the potential effects on energy consumption and greenhouse gas emissions. This complementary assessment provided a broader data set for evaluating the overall effectiveness and sustainability of the PP2 pilot project.

PP3 AIN

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: Field Operational Testing was conducted through a structured sequence of steps that reflected realistic operational conditions and aligned with the system's intended use. The process began with the preparation of the testing environment, including configuration of user accounts, activation of relevant modules, and loading of representative datasets covering notifications, accidents, investigations, and safety recommendations. Initial tests were performed in a controlled virtual environment to verify system stability, module interactions, and user-access controls. Once core functionality was validated, testing progressed to a real operational environment, where actual workflows, such as entering notifications, documenting accidents, uploading investigation files, and generating reports were executed by operational staff. A hybrid environment was used in the final phase to combine real data with controlled scenarios, enabling validation of edge cases

and ensuring system robustness. Roles during FOT were clearly defined. Technical staff were responsible for system configuration, monitoring system logs, addressing technical issues, and ensuring secure operation. Operational users performed real-world tasks within the application, validating usability, workflow accuracy, and compliance with established procedures. External stakeholders would be involved only if the Agency decides that their participation is required.

DATA AND FEEDBACK COLLECTION: Data and feedback collection relied on a combination of automated monitoring and structured user input. Several categories of operational data were gathered:

- System logs capturing authentication events, module usage, document uploads, error messages, and performance indicators such as response times and concurrent user activity.
- Operational performance data reflecting how users interacted with modules for notifications, accidents, investigations, and safety recommendations.
- User feedback collected through direct communication, structured comments, and observations during testing sessions, focusing on usability, workflow clarity, and functional completeness.

Data collection tools included built-in logging mechanisms, administrative dashboards, and manual feedback forms. The testing team also reviewed audit logs to verify correct behavior of authentication, authorization, and session management features.

PP4 ERF – Port of Marghera

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: To verify the various development phases of Minosse, field tests were conducted. After the initial implementation of the infrastructure resources, two ERF operators, equipped with the tools purchased through the CROSSFREIGHT project, went into the field to simulate a monitoring activity. This allowed them to work not only on the system logic, but also on its usability. Any anomalies encountered in the system were logged. The recording and consistency of the data entered by the operators were verified by the Technical Sector Manager, who operated from a

fixed location. Once sufficient data was obtained, checks were performed on the tracking and management of system anomalies.

DATA AND FEEDBACK COLLECTION: The heart of the Minosse system is a Postgress-type database, which has proven to be the best at managing georeferenced elements. At each verification step, the data collected in the field were entered into the database and analyzed at a later stage. At each testing stage, feedback via MS Teams was provided to the Minosse developer regarding any malfunctions and/or improvements to be made to the system.

PP6 Sangritana – Terminal Saletti

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: For the FOT, the test environment was hybrid, starting from a virtual environment, then after the simulation conducted for the software was successful, the real FOT was conducted. On the 14th and 15th of March 2026, the general real FOT was conducted in place, by adding the sensors to actual trains and monitoring the rail traffic in the compound. The roles of operators were the following: Marco Grifone was in charge of both the virtual and the real FOT realization; Sandro Imbastaro was in charge of the permits, the authorization to proceed, the monitoring of the trains and the communication; Luigi Di Cicco, was both in the real FOT the actual frontend user and the utilizer of the platform; Gianni Moretti kept monitoring, both in the virtual and real FOT, the performance of the platform in relation to safety, security and regulation concern, in order to evaluate a full implementation of the solution in the near future after the project end.

DATA AND FEEDBACK COLLECTION: The types of data were the following:

- Virtual FOT: simulated data on trains, with ETA, ATA, ETD, ATD, performance indicators including the simulated gate passing and status changes for both actual trains and single wagons;
- Real FOT: actual trains, with real ETA, ATA, ETD, ATA, performance indicators including the gate passing monitoring, and status changes for the selected trains.

PP7 Port Authority of Sibenik – Port of Sibenik

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: Chronological steps:

1. Preparation Phase
    - Finalization of Excel templates
    - Training sessions
    - Definition of KPIs and targets
2. Daily Operational Testing (2 months)
    - Manual entry of train arrivals/departures
    - Entry of loading/unloading times
    - Monitoring of platform occupancy
3. Weekly Review
    - Analysis of pivot tables
    - KPI tracking via line charts
    - Identification of bottlenecks
4. Final Evaluation
    - Comparison against baseline performance
    - Stakeholder feedback analysis

Test environment:

- Real operational environment
- Single railway platform
- Daily train operations
- Shared Excel environment

Roles:

- Operators: daily data entry
- Port staff: validation and monitoring
- Coordination team: KPI evaluation.

DATA AND FEEDBACK COLLECTION:

Types of data collected:

- Train arrival/departure times
- Number of wagons/containers
- Loading/unloading duration
- Platform occupancy
- Error occurrences
- Stakeholder feedback (Excel forms)

Tools used:

- Excel tables
- Pivot tables
- Charts (bar, line)
- Conditional formatting

Limitations:

- Manual data dependency
- Risk of delayed data submission
- Limited automation

Mitigation:

- Clear submission deadlines
- Weekly validation reviews

PP8 Transagent – Port of Rjieka

OPERATIONAL PROTOCOL FOR FIELD OPERATIONAL TESTING: Field Operational Testing followed a structured process including train data entry, real-time monitoring of train movements, verification of operational events such as arrivals and departures, and automated notification distribution to relevant

stakeholders. Testing was performed under real operational conditions with the participation of operational staff and technical personnel.

DATA AND FEEDBACK COLLECTION: During testing, several types of data were collected, including system performance logs, operational indicators, and user feedback. Data were gathered through system monitoring tools and feedback from operational users. Some limitations in accessing external operational data were identified but managed through alternative validation procedures.

IV. Evaluation and consolidation: success criteria and evaluation; conclusions and lessons learned

PP1 Fondazione ITL – Port of Ravenna

SUCCESS CRITERIA AND EVALUATION: The success of the Field Operational Testing (FOT) was evaluated using Key Performance Indicators (KPI) to measure technical performance, operational efficiency, and compliance with the objectives defined in Deliverable 2.1.

The monitored KPIs include:

- *Infrastructure occupancy and workload:* station, parking zones, operational teams;
- *Stop durations*: terminal, station, yard;
- *Train traffic and operations*: number of trains, export/import accessories and secondary trains, planning time, percentage of served and eligible trains.

Analysis of these indicators confirmed that the system meets the required levels of performance, reliability, and operational correctness, achieving the FOT objectives.

CONCLUSIONS AND LESSONS LEARNED: The development and Field Operational Testing (FOT) activities confirmed the effectiveness and adequacy of the implemented solution. Functional requirements, data, and input/output flows were validated, while the system's performance proved consistent with the initial

objectives, ensuring effective integration with existing systems and platforms. The evaluation of results was supported by the use of Key Performance Indicators (KPIs), allowing an objective analysis of operational performance. Minor issues were identified during testing, mainly related to planning logic and certain aspects of the interface, which were adjusted to facilitate operational use. Among the lessons learned, it is evident that a clear definition of requirements and KPIs is essential for objectively assessing system performance. The solution has proven scalable and adaptable to future scenarios, and it is recommended to continue monitoring KPIs during real operational phases to ensure reliability, robustness, and consistency of results over time.

PP2 Adriafer – Port of Trieste

SUCCESS CRITERIA AND EVALUATION:

SUCCESS CRITERIA AND EVALUATION – ENHANCED MULTIDIMENSIONAL ASSESSMENT

The evaluation of the PP2 Adriafer pilot progressively expanded beyond the verification of technical interoperability between Sinfomar and Trainshunt. The Field Operational Test demonstrated that the strategic relevance of the solution depends not only on whether the ICT modules operate correctly, but also on whether their deployment produces measurable organisational, economic and sustainability-related benefits and provides a sound basis for future investment and scaling decisions.

Technical and operational performance remained the first level of assessment, producing the following results:

- Technical KPIs: Achieving 100% synchronization of wagon data between Sinfomar and Trainshunt.
- Operational KPIs: A measurable reduction in the time required to process shunting cancellations.
- Compliance: Full alignment with the "To-Be" scenario and the interoperability standards defined in Activity 2.1.

A second evaluation layer was, then, introduced to assess cost-effectiveness and resource efficiency. Attention was paid to the reduction of fragmented information exchanges, duplicated communications and manual activities, and to the potential optimisation of personnel time and operational resources resulting from integrated digital information flows.

The assessment was further extended to environmental and decarbonisation-related performance. The objective was to establish a methodological relationship between improvements in operational efficiency and their potential effects on energy consumption and greenhouse gas emissions. This allows the pilot to be considered not only as a digitalisation measure, but also as a possible enabling factor for the wider decarbonisation of rail-port logistics processes.

In addition, the evaluation introduced Do No Significant Harm-oriented criteria, aimed at identifying potential negative effects or trade-offs associated with technological deployment, and human-centric criteria, aimed at verifying that the digital solution supports rather than undermines operators' activities. The latter dimension considers usability, transparency, adequate human oversight, training requirements and the need to avoid discriminatory or exclusionary consequences in human-machine interaction.

Finally, governance criteria were incorporated into the assessment. These include data quality and traceability, allocation of responsibilities, data ownership, access control, interoperability governance, stakeholder accountability and the capacity to maintain a structured and auditable KPI monitoring system over time.

The integration of these dimensions transformed the assessment from a predominantly technical validation exercise into a multidimensional decision-support framework. Specialist external expertise supported the structuring of relevant economic, operational, environmental and governance indicators

and their connection with sustainability-management practices already being progressively developed within Adriafer's corporate framework.

This approach provides a more robust basis for determining whether the pilot solution should be scaled, replicated or further invested in. It also increases the transferability of the CROSSFREIGHT methodology, as the same evaluation logic can be applied to different ICT solutions and logistics nodes even where the underlying technologies differ.

CONCLUSIONS AND LESSONS LEARNED: The development and FOT activities confirmed that the integration of shunting procedures into the Port Community System is essential for the "Smart Port" vision.

- Achievements: The elimination of fragmented manual communications has significantly increased operational transparency and coordination. From a broader sustainability perspective, the pilot also highlighted potential environmental benefits linked to more efficient operational planning and resource use, while improved data availability and traceability strengthened governance and accountability. From a human-centric perspective, the digitalisation of information flows supports operators by reducing repetitive manual exchanges and providing more consistent and accessible operational information.
- Lessons Learned: A precise definition of "Wagon Master Data" is the critical enabler for any further automation.
- Recommendations: It is recommended to proceed with a full-scale rollout to all port stakeholders to maximize the network effect of digital integration.

The methodological enhancement introduced through the Adriafer pilot represents an additional result of the CROSSFREIGHT experimentation process. The main innovation does not consist solely in the identification of additional environmental indicators, but in the development of a structured decision-support logic connecting technical performance, operational efficiency, economic sustainability, climate

and environmental performance, human-centric digitalisation and governance. This approach is particularly relevant for the exploitation phase of the project. A technically successful ICT solution does not automatically represent a scalable or strategically sustainable investment. Replication decisions require evidence concerning implementation costs, organisational impacts, expected operational benefits, environmental contribution, governance requirements and the conditions necessary for safe and inclusive adoption by operators. The multidimensional evaluation framework tested and refined through PP2 can therefore be considered as a potentially exploitable methodological result in its own right. It may support railway undertakings, port authorities, terminal operators and other logistics stakeholders in evaluating future digitalisation investments and comparing alternative technological solutions using a common decision-support structure. From this perspective, the CROSSFREIGHT experience moves from the validation of individual ICT pilots towards the definition of a transferable methodology for assessing the overall value and sustainability of digital innovation in rail-port logistics.

PP3 AIN

SUCCESS CRITERIA AND EVALUATION: The success of the Field Operational Testing was evaluated using criteria that reflected both the technical performance of the system and its alignment with the operational objectives defined in Activity/Deliverable 2.1. Technical performance indicators focused on system stability, response times, error-free execution of workflows, correct functioning of all modules, and the reliability of document uploads, data filtering, and export functions. Procedural and operational effectiveness was assessed through the accuracy and completeness of real-world tasks performed by users, including the entry of notifications, accident documentation, investigation tracking, and management of safety recommendations. User interactions were monitored to confirm that workflows were intuitive, consistent, and aligned with established procedures. Compliance with the objectives defined in Deliverable 2.1 was confirmed through validation of modular architecture, role-based access control, audit logging, responsive design, and the ability to import historical data from Excel files for the years 2022–2025.

CONCLUSIONS AND LESSONS LEARNED: The development and testing activities resulted in several key achievements. All planned modules—Notifications, Accidents and Incidents, On-Site Investigations, Suicides and Attempts, Investigations, and Safety Recommendations—were successfully implemented with full functionality, including document upload, data filtering, reporting, and statistical visualization. The modular architecture proved effective, allowing flexible activation of components depending on deployment needs. The import of historical data from Excel files was completed successfully, ensuring continuity of operational records. User training was delivered as planned, enabling smooth adoption of the system.

PP4 ERF – Port of Marghera

SUCCESS CRITERIA AND EVALUATION: Once the single processes that comprise Minosse had been tested, a final test was conducted, involving the entire system. This phase verified multiple aspects, including the absence of critical issues that had emerged in previous phases, process repeatability, the correct implementation of barriers to prevent incorrect data entry, and data alignment between mobile and fixed stations.

CONCLUSIONS AND LESSONS LEARNED: The development of Minosse did not encounter any significant challenges, given the extensive experience of both ERF staff and the company staff who enabled its programming. Furthermore, an in-depth preliminary analysis allowed us to identify from the outset not only the kind and type of data to be collected, but also the kind of database and its structure and the best technologies to make Minosse's development easier to manage, both during this design phase and during further development. In a world where the problem is no longer data acquisition, but its use, Minosse, through further developments, proposes itself as an innovative tool for monitoring the railway infrastructure of small networks and private connections.

PP6 Sangritana – Terminal Saletti

SUCCESS CRITERIA AND EVALUATION: The key criteria for the evaluation of the FOT was based on the reliability of the tracking. By tracking the trains passage, the system can easily evaluate the traffic and manage it without human intervention. The main point of the system is to track each status change of the trains and at the same time providing the security of parked trains. The degree of compliance with the objectives defined in Activity 2.1 was high.

CONCLUSIONS AND LESSONS LEARNED: The main results of the development and testing activities led to the realization of a low cost solution to track and trace the rail traffic and trains' statuses changes within a rail compound. The lessons learned are important, as it was possible to appreciate the quality of beacon gateways, both in terms of practical usage, the low cost, and the ease of installation. In particular, the portable nature of the beacon gateways can also lead to portable installations. The key limitation learned is related to the wagons and trains tracking devices, which have to be manually inserted into the wagon and into the locomotive. The key point there will be to install permanent devices on the shunting locomotives, while it will be possible to have the rear end devices installed on the rear lights of the train composition.

PP7 Port Authority of Sibenik – Port of Sibenik

SUCCESS CRITERIA AND EVALUATION: Technical performance indicators:

- 15% increase in daily train throughput
- 20% reduction in average wagon handling time
- Reduction in loading errors
- Positive stakeholder feedback

Procedural effectiveness:

- Improved coordination
- Reduced scheduling conflicts
- Better visibility of platform occupancy

Compliance:

All objectives defined in Activity 2.1 were addressed:

- Capacity optimization
- Loading efficiency improvement
- Stakeholder coordination enhancement
- Low-cost scalable solution

CONCLUSIONS AND LESSONS LEARNED: Key achievements:

- Structured data management in railway operations
- Improved transparency of train scheduling
- Quantifiable KPI monitoring
- Strengthened coordination between stakeholders

Main issues identified:

- Dependence on manual data entry
- Need for stricter data validation
- Risk of version control issues

Lessons learned:

- Standardization significantly improves operational efficiency
- Even low-complexity ICT tools can deliver measurable improvements
- Future scaling should consider semi-automation or PCS integration
- Data governance procedures must be clearly defined

Next phase should consider partial automation and integration with port digital platforms to further reduce manual workload.

PP8 Transagent – Port of Rijeka

SUCCESS CRITERIA AND EVALUATION: The success of the Field Operational Testing was evaluated based on system stability, accuracy of real-time train monitoring, and improvement of operational information

flow. The system successfully supported operational processes and improved communication between stakeholders, confirming the objectives defined in Activity 2.1.

CONCLUSIONS AND LESSONS LEARNED: The pilot demonstrated that the FIS system can significantly improve operational visibility, information exchange, and coordination in railway freight transport. The main challenges were related to system interoperability and integration with existing operational platforms. The pilot confirmed the importance of stakeholder coordination, user training, and continuous system testing for successful deployment.

V. Video documentation

At the original reporting cut-off date, part of the visual documentation associated with the pilot actions was still undergoing production and final validation. For this reason, the technical and procedural evidence available at that stage was prioritised in order to ensure timely submission of the deliverable.

Following the completion of the remaining audiovisual contributions by the project partners, the deliverable has been updated to incorporate the final video evidence. This integration strengthens the overall quality and completeness of the Field Operational Test documentation by complementing quantitative KPIs, technical descriptions and operator feedback with direct visual evidence of the solutions and workflows tested.

The updated video documentation also has a specific exploitation value. It provides an accessible demonstration of the project results for stakeholders that were not directly involved in the pilot actions and facilitates the communication, transferability and replication of the CROSSFREIGHT solutions within WP3.

Click here to view the videos of pilot actions.

4. Conclusions

The successful completion of the Field Operational Tests (FOT) within Activity 2.2 marks a fundamental milestone for the CROSSFREIGHT project, transitioning the strategic vision of digitalized rail-port logistics into a series of validated operational environments. This comprehensive reporting phase, which gathered detailed technical and procedural feedback from all project partners, demonstrates a clear and shared trajectory toward the structural modernization of the Adriatic-Ionian freight corridors. The collective evidence suggests that the "To-Be" scenarios envisioned in the previous phases have been effectively translated into functional ICT modules, capable of addressing long-standing inefficiencies in cross-border and port-rail transitions. Throughout the execution of the various pilots—ranging from the shunting digitalization in the Port of Trieste led by Adriafer to the advanced logistics tracking and capacity management solutions developed by ITL, ERF, and other partners—a common technological foundation has emerged, built on interoperability, standardized data exchange, and the "Single Source of Truth" principle.

The primary strength of the project lies in its ability to harmonize diverse logistical needs through a Service-Oriented Architecture (SOA) approach. The pilots have consistently shown that replacing fragmented, manual communication methods, such as paper-based lists and verbal authorizations, with synchronized digital workflows significantly reduces "dead times" and human error. In particular, the implementation of unified registries for wagon technical data and the automation of train composition flows have empowered operators with real-time visibility, enhancing the overall agility of the logistics chain. Furthermore, the methodological rigor provided by the FESTA framework ensured that the technical validation remained anchored to practical operational requirements, allowing for a seamless integration of new software modules without disrupting existing port and rail traffic. This synergy between institutional stakeholders, technical providers, and ground operators has fostered a collaborative digital culture that is essential for the long-term sustainability of the project results.

However, the execution phase also brought to light several systemic challenges and weaknesses that define the current limitations of digital integration. A recurring issue across the different pilot sites is the inherent difficulty in bridging modern, API-driven web services with the diverse legacy systems still utilized by various national rail operators and smaller terminalists. This “digital gap” occasionally creates data latency, which, in high-density nodes, can still lead to localized operational friction. Additionally, the pilots underscored that the success of technical innovation is deeply dependent on the quality of the initial master data; any inconsistency in the static data of wagons or infrastructure can propagate through the automated system, highlighting that data cleaning and standardization are necessary prerequisites for any future scaling. From an organizational perspective, the transition to digital workflows also revealed the importance of change management, as the shift from traditional coordination to strictly digital protocols requires sustained training and the adaptation of internal safety and administrative procedures. The lessons learned during these Field Operational Tests provide a strategic roadmap for the subsequent stages of the project. It is evident that while the technical feasibility of the CROSSFREIGHT modules has been proven, their broader impact will depend on the ability to scale these solutions across the entire corridor network. This requires not only technical scalability but also a policy-driven push toward common European data standards that can facilitate smoother cross-border interoperability. The success of the pilots in reducing process execution timing and increasing transparency provides the empirical evidence needed to support these future recommendations. As the project moves into the final assessment phase, these findings will serve as the core data for quantifying the socio-economic and environmental benefits of the digital transition, particularly in terms of CO2 reduction and optimized resource utilization.

For the PP2 pilot (Adriafer), a more comprehensive assessment was carried out with the support of external specialist expertise, aimed at integrating the technical and operational results of the pilot project with a structured evaluation of cost-effectiveness, resource efficiency and environmental performance. The assessment provided a methodological framework for linking the operational improvements generated by the digitalisation of sorting processes to their broader economic and environmental implications.

The analysis carried out for the PP2 pilot provided a broader understanding of the value and potential of the digital solution beyond its technical performance. It showed that the benefits of integrating and digitising shunting information flows can be considered not only in terms of interoperability and operational effectiveness, but also through their implications for cost-effectiveness, resource efficiency and environmental performance. In particular, the analysis made it possible to identify how reductions in processing times, manual activities and duplicated information exchanges may contribute to a more efficient use of operational resources, while also providing a methodological basis for linking operational improvements with potential effects on energy consumption and greenhouse gas emissions.

The analysis also highlighted that successful technical validation does not, by itself, guarantee the scalability or long-term sustainability of a digital solution. For future deployment and replication, additional aspects need to be considered, including implementation costs, organisational impacts, expected operational benefits, environmental contribution, data governance and accountability, as well as usability, human oversight, training and the conditions for safe and inclusive adoption. In this respect, the multidimensional assessment provided a decision-support perspective that helps identify the conditions under which a validated digital solution can generate broader and sustainable value.

Finally, the experience gained through the PP2 assessment demonstrated that this evaluation approach can represent a transferable methodological result of the CROSSFREIGHT project. By connecting technical and operational evidence with economic, environmental, resource-efficiency, human-centric and governance considerations, the approach can support future decisions on scaling, replication and investment in digital solutions for rail-port logistics.

Regarding the visual documentation of the pilot activities, it should be noted that comprehensive video documentation is not available at this current reporting stage. This absence is primarily due to the strict safety and security protocols governing active port and railway areas, which restricted extensive filming during the critical Field Operational Test phases to avoid any interference with live shunting and mainline operations. Furthermore, as some ICT modules reached their full operational stability towards the end of the reporting period, the consortium prioritized the consolidation of technical KPIs and procedural



validation over multimedia production. However, to ensure full transparency and fulfill the project's dissemination requirements, the partners have developed a contingency approach. Detailed screencasts of the software interfaces, technical walkthroughs, and recorded demonstration sessions involving key users will be produced and submitted in the upcoming project intervals, providing a clear visual record of the digital interactions and the operational workflows achieved during the CROSSFREIGHT pilot actions.