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Transforming
Europe's Rail Freight

D24.1

Preparation of standardisation and demonstration

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1 Executive Summary

Deliverable D24.1 documents the work carried out within WP24 – Preparation of demonstration and standardisation for seamless freight – which provides the foundation for the coordinated execution of the Seamless Freight demonstrations in WP33 (Showcase Seamless Corridor) and WP34 (Showcase Seamless Multimodal). In line with the objectives of FP5-TRANS4M-R, WP24 ensures that the technical enablers developed across the Seamless cluster can be validated in an integrated and interoperable operational context.

The objective of WP24 is to bridge the gap between technical development and operational demonstration. While Work Packages WP26–WP32 focus on individual functionalities—such as planning, dispatching, monitoring, multimodal integration and data exchange—WP24 provides the structure and alignment required to integrate these elements into coherent demonstration scenarios.

WP24 is organised around three core tasks. Task 24.1 ensures coordinated demonstration setup and alignment through the Demonstration Execution Plan. Task 24.2 addresses data management, including data preparation, harmonisation and alignment with common data models and data space concepts. Task 24.3 focuses on standardisation, identifying impacts on existing frameworks and ensuring coordination with ERA, the System Pillar and sector stakeholders.

A uniform analytical structure is applied across all demonstration groups, covering scope, setup, data needs, standardisation aspects and dependencies. This ensures consistency and traceability across the Seamless demonstration landscape. The demonstration groups represent integrated scenarios reflecting real operational processes across rail freight corridors and multimodal chains. By bundling individual use cases, WP24 enables the validation of system interactions and cross-domain dependencies, rather than isolated functionalities.

Overall, D24.1 provides the structured foundation required to execute the Seamless demonstrations in a consistent and standards-aligned manner, supporting the validation of FP5-TRANS4M-R solutions under realistic conditions and contributing to future interoperability and standardisation in European rail freight.

Keywords: demonstration, interoperability, framework

2 Abbreviations & Acronyms

Abbreviation / Acronym	Description
DG	Demonstration group
API	Application Programming Interface
CA	Certification Authority
CDM	a) Conceptual Data Model b) Collaborative Decision Making
ERC	European Railway Checkpoint
ERDS	European Rail Data Space
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
EU-Rail	Europe's Rail Joint Undertaking
FA	Flagship Area
FP	Flagship Project
ILUs	Intermodal Loading Units
IVG	Intelligent Video Gate
KPI	Key Performance Indicator
MAWP	Multi-Annual Work Plan
PCS	Path Coordination System
RailwayCDM	Railway Collaborative Decision Making
RFID	Radio Frequency Identification
RU	Railway Undertaking
ScanMed	Scandinavian-Mediterranean Transport Corridor
TAF TSI	Telematics Applications for Freight Technical Specification for Interoperability in rail freight
TAO	Track Assignment Optimizer
TE	Technical Enablers
TMS	Traffic Management System
TPS	Train Planning System
TRL	Technology Readiness Level
WP	Work Package
Yard-CMS	Yard Capacity Management System
YCS	Yard Coordination System
YDS	Yard Dispatching System
WOBU	(CEIT to confirm) Wagon On-Board Unit?
UWB	(CEIT to confirm)
RUE	(CEIT to confirm)
FDS	(CEIT to confirm) Federated Data Space???

3 Background

The present document constitutes the Deliverable D24.1 "Preparation of standardisation and demonstration" in the framework of the Flagship Project FP5 – TRANS4M-R as described in the EU-RAIL MAWP and contributes as well to the Flagship Project FP5 – TRANS4M-R as described in the EU-RAIL MAWP.

Seamless Freight cluster of FP5 – TRANS4M-R aims to demonstrate how digital, harmonised and interoperable processes can improve international rail freight operations, covering planning, dispatching, monitoring, multimodal integration and automated inspection. As defined in the Grant Agreement, WP24 serves as the central preparatory work package responsible for ensuring that the demonstrations planned in WP33 (Showcase Seamless Corridor) and WP34 (Showcase Seamless Multimodal) can be executed in a coordinated, data-ready and standards-compliant manner throughout the first call of the project.

WP24 consolidates inputs from all Seamless technical work packages (WP26–WP32), the specification phase (WP25) and the demonstration work packages (WP33 and WP34). It provides the organisational backbone for demonstration planning and execution. Through its three tasks - Task 24.1 Setup and Maintenance of Demonstrations, Task 24.2 Data Management for Development and Demonstration, and Task 24.3 Standardisation Input - WP24 ensures that technical developments are not validated in isolation but tested as part of an integrated, cross-border and multimodal operational chain.

This deliverable presents the preparatory work performed by WP24 and provides the structured foundation on which the demonstration activities of WP33 and WP34 were implemented.

4 Objectives

The objective of this deliverable is to document how WP24 prepared, structured and aligned the Seamless Freight demonstrations, ensuring that the technical enablers developed across WP26–WP32 can be validated under realistic operational conditions within WP33 and WP34.

Beyond documenting preparatory activities, the deliverable establishes a clear methodological framework for transitioning from technical development to integrated demonstration. This includes the systematic bundling of individual use cases into coherent demonstration groups, reflecting end-to-end operational processes across rail freight corridors and multimodal transport chains.

To support this objective, WP24 applies a uniform analytical structure to each demonstration group, covering scope, demonstration setup and alignment, data needs and preparation, standardisation aspects and dependencies. This approach ensures consistency across all demonstration areas and enables a structured assessment of how different technical enablers interact within a shared operational context.

A key objective is to ensure that all demonstrations are data-ready and interoperable. WP24 therefore identifies and prepares the required datasets, supports data provision agreements between stakeholders and ensures alignment with common data models and, where applicable, federated data space concepts. This enables the involved systems to operate on a consistent information basis and supports the evaluation of data-driven functionalities such as planning, dispatching and monitoring.

In parallel, the deliverable aims to capture standardisation-relevant findings emerging from the preparation of the demonstrations. By analysing the interaction between systems, data and operational processes, WP24 identifies potential impacts on existing frameworks such as TAF TSI and EDIGES and prepares the ground for further alignment with ERA, the System Pillar and sector stakeholders.

Finally, the deliverable establishes the foundation for evaluating the Seamless demonstrations at system level. By clarifying dependencies, interfaces and interaction points between technical enablers, WP24 enables the assessment of integrated performance improvements, rather than isolated functionalities, thereby directly supporting the objectives defined in the Grant Agreement.

4.1 Link between GA objectives and chapters in the Deliverable

The table below links the tasks described in the Grant Agreement for the related WP32 objectives to the respective chapters of this deliverable that feature these elements.

Task (GA)	Task definition from GA (WP24)	Output of deliverable
T24.1	Setup and Maintenance of Demonstrations: Within this project, a variety of demonstrations is conducted to prove the planned TRL. Technical developments and interactions between components and partners are set up in different demonstration sites and situations. All partners contribute to the development of a demonstration execution plan that aligns planning, timing, execution, and evaluation. It covers aspects of requirements, goals, results, involved partners, risks, and components to be demonstrated.	This deliverable provides the coordinated setup and alignment for all demonstration groups. It defines the scope, operational scenarios, and demonstration plans for the Seamless Corridor and Seamless Multimodal showcases (see Chapters 4.2.2, 4.3.2, 4.4.2, and 5.2.2).
T24.2	Data Management for Development and Demonstration: The baseline data required by enabler/demonstrators from the operators (IM/RU/CTO) will be specified for handover based on specific data provision agreements. A description document of the source data and underlying models is created for conversion to the different internal models of the demonstrator systems. Models and formats crucial for system integration are shared with Destination FA1 for the Federated Data Space.	The deliverable documents the results of the data needs, preparation steps, and harmonisation efforts regarding the preparation and setup of demonstrations for each demonstration group. It shows the alignment with common data models (RailwayCDM) and addresses some data exchange requirements between technical enablers (see Chapters 4.2.3, 4.3.3, 4.4.3, and 5.2.3).
T24.3	Standardisation input: The new concepts, functions, and seamless interactions might require an extension of the existing standards (e.g., TAF TSI and EDIGES). In coordination with Destination FA1-TT, the input coming from the Seamless WPs is analysed and suggestions are prepared.	This deliverable identifies standardisation-relevant findings emerging from the demonstration preparations. It captures potential impacts on frameworks like TAF TSI and prepares the foundation for alignment with the System Pillar and ERA (see Chapters 4.2.4, 4.3.4, 4.4.4, and 5.2.4).

Demonstration group allocation process

As previously mentioned in this report, it was necessary to aggregate the individual use cases to provide a meaningful assessment of the project's impact on KPI – such as reducing transportation time and operational dwell times. Thus, the project team mapped the interdependencies between technical enablers.

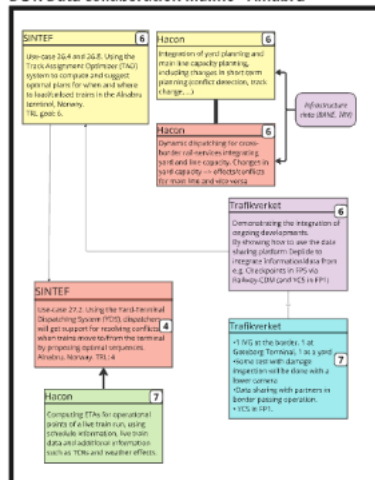
This work led to the allocation of use cases, bundled into four distinct Demonstration Groups (DGs), creating a clear structure for the Showcase Seamless Corridor (WP33) and the Showcase Seamless Multimodal (WP34).

Final demonstration group structure

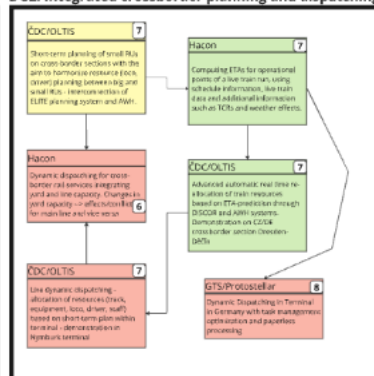
The resulting groups represent the practical application of the "Seamless" vision along the reference corridors:

- DG1: Integrated Capacity Planning (Malmö – Alnabru): A cross-border showcase focusing on data sharing and integrated capacity planning, mainly between Sweden and Norway.
- DG2: Integrated Cross-border Short-Term Planning and Dispatching: Focuses on harmonizing resource deployment for Railway Undertakings (RUs) and optimizing terminal handling through real-time resource reallocation.
- DG3: Standardised European Railway Checkpoints: Demonstrates the deployment of ERCs/IVGs and data exchange across Germany, Sweden, the Netherlands, and Spain. This group showcases the automation of wagon set identification and dangerous goods detection, utilising a common Conceptual Data Model (CDM).
- DG4: Seamless Multimodal Transport (WP34): An integrated showcase demonstrating demand-responsive routing and dynamic capacity allocation across multimodal chains and major intermodal operators.

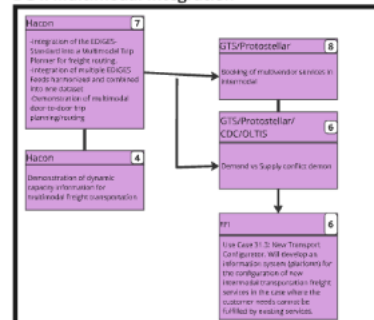
DG1: Data collaboration Malmö - Alnabru



DG2: Integrated crossborder planning and dispatching



DG4: Multimodal Integration



DG3: Standardised European Railway Checkpoints: IVG technology and image processing (AI) on cross borders, yards and terminals; Data exchange in Can Tunis Checkpoint

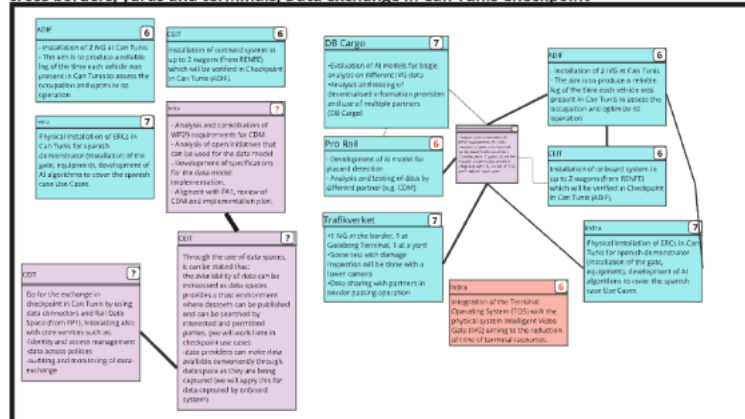


Figure 2 Allocation of individual WP use cases into four demonstration groups focused on (1) data collaboration between Malmö and Alnabru, (2) integrated cross-border planning, (3) standardized European Railway Checkpoints, and (4) multimodal integration.

By organising the individual WP use cases into these four DGs, see Figure 2, the project transitioned from technical development to operational validation. This approach allows for a structured assessment of the synergies between different technologies and provides a field-tested proof point for the developments within Seamless, see Figure 3. This deliverable covers the DG 1, 2 and 3, while DG4 is covered in D34.1.

The demonstration groups further provide a geographical perspective in relation to the transport corridor approach, and the ScanMed transport corridor as mentioned in the grant agreement.

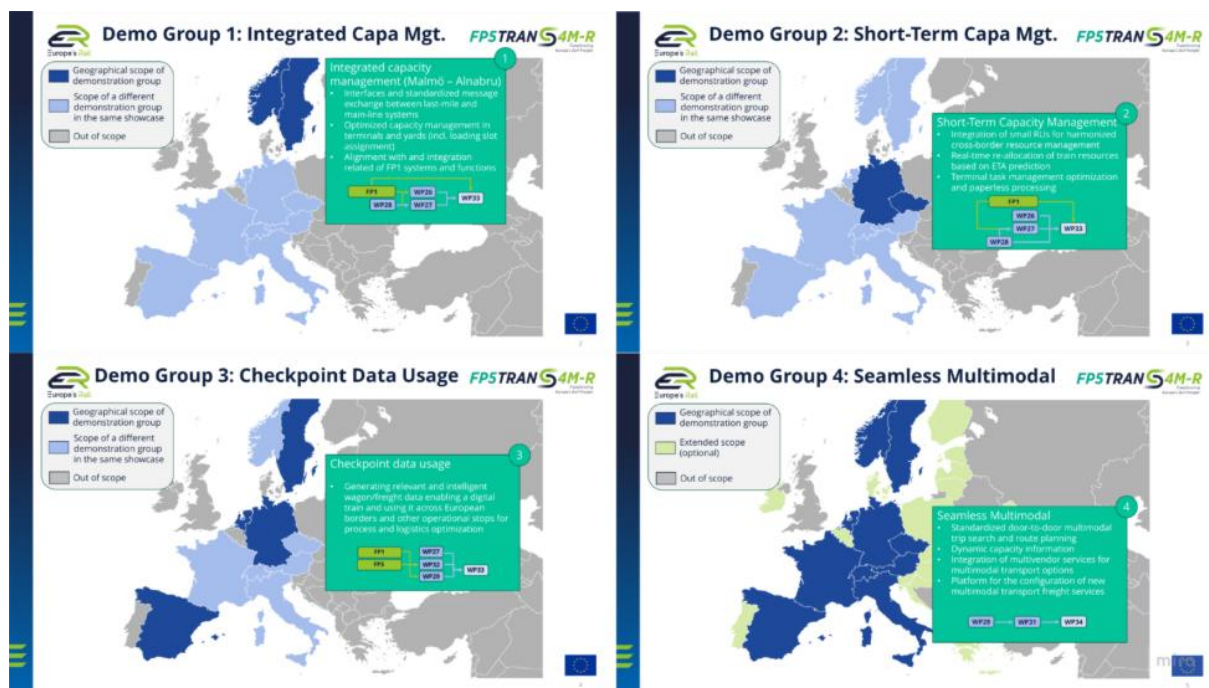


Figure 3 The thematic consolidation of individual WP use cases into four primary demonstration groups, demo groups 1-3 (WP33 showcase) and demo group 4 (WP34 showcase).

5.2 Demo Group 1 – Integrated Capacity Planning

5.2.1 Scope

- Storyline of the Demo Group
- Overview of demonstrated technical functionalities
- Involved partners and their role within the Demo Group
- How do the systems and partners interact with each other / efforts towards interoperability

Demo Group 1 addresses Integrated Capacity Planning in a cross-border rail freight context, using the Malmö–Alnabru flow on the Scandinavian–Mediterranean (ScanMed) corridor as the main reference case. The overall purpose of the demonstration group is to show how improved data exchange and system interoperability can support better coordination between yard operations, terminal processes and mainline planning, thereby enabling more robust and efficient corridor operations. The demonstrator was selected because it combines last-mile, yard and mainline processes in a realistic operational setting and because it offers a strong use case for the interaction between developments from FA5 and FA1.

The storyline of Demo Group 1 is centred on the idea that deviations from plan must be detected early and shared quickly enough to enable coordinated replanning across the transport chain. Instead of treating yard, terminal and mainline systems as isolated information silos, the demonstration group brings together several technical enablers in

order to create a more connected operational environment. In this way, local events such as delays, asset constraints, train composition changes or checkpoint observations can be propagated to other actors and systems, allowing downstream decisions to be taken earlier and on a better information basis. The expected result is improved decision-making, reduced operational dwell time and faster response to disturbances.

From a functional perspective, Demo Group 1 combines several complementary capabilities. A first element is integrated capacity management, linking last-mile and mainline systems through standardised message exchange. A second element is dynamic yard capacity management, where Yard-CMS and the Yard Coordination System (YCS) support the coordination of local yard planning with broader network management processes. A third element is real-time data capture, using Intelligent Video Gates (IVGs) and RFID readers to capture logistics-relevant information such as wagon identity, wagon sequence and dangerous goods information. In addition, the demonstration includes predictive planning through ETA/ETD-related functions, and track assignment and dispatching through tools such as TAO and YDS in the broader Malmö-Alnabru operational chain. Taken together, these functionalities illustrate how integrated data handling can support both planning stability and more dynamic operational control.

The main partners involved in the demonstration group represent both operational stakeholders and technology providers. Trafikverket contributes checkpoint and trackside data capture, in particular through IVG installations. RISE contributes the YCS and RailwayCDM-related integration logic. Hacon contributes Yard-CMS and prediction-related functionalities. KTH contributes ETD prediction models for Malmö yard operations. SINTEF contributes optimisation and dispatching tools such as TAO and YDS, particularly relevant for the Alnabru side of the use case. The interaction of these contributions reflects the intended collaboration between FA5 developments and relevant FA1 capabilities, especially in the area of network and yard coordination.

A central aspect of the scope is therefore not a single stand-alone application, but the interoperable interaction between systems. D33.1 positions the Malmö-Alnabru demonstration as a key example of FA5-FA1 collaboration, in which YCS, Yard-CMS and related data exchange mechanisms are used to demonstrate how local yard planning can be connected with broader network management. The demonstration also draws on the common data and exchange concepts developed in WP32 and on the alignment work between FA5 and FA1 around YCS, CDM, ERDS and Yard-CMS. Demo Group 1 therefore has a dual role within WP24: it is both an operational demonstration of integrated capacity planning and a preparation case for demonstrating how seamless data exchange can enable practical interoperability between different technical enablers and organisational actors.

5.2.2 Demonstration setup

Under Task 24.1, WP24 prepared Demo Group 1 by establishing and continuously updating the demonstration framework needed to align partners, sites, technical components, timelines and dependencies. In line with the general WP24 approach, the preparation of Demo Group 1 was organised through the Demonstration Execution Plan and through a common analytical structure covering scope, setup, data needs, standardisation aspects and dependencies. For this demonstration group, the main objective of the setup and alignment work was to ensure that the Malmö-Alnabru use case could evolve from an early specification and requirements phase into a coordinated cross-border demonstration involving multiple systems, organisations and data interfaces.

The preparation started from the use-case and requirements work carried out in WP24 and WP25 during the earlier project phase. These activities defined the operational problem space, identified the relevant technical enablers and clarified which interactions between yard, terminal and mainline systems should be demonstrated. Based on this, the project moved into a structured alignment phase in which the individual developments from WP26–WP32 were mapped into demonstration groups. In the case of Demo Group 1, this bundling was driven by the common objective of showing how integrated capacity planning and real-time information exchange can improve decision-making along a corridor-oriented freight flow. This also made Demo Group 1 the natural place to demonstrate the interaction between FA5 developments and selected FA1 developments related to network management.

A key milestone in the setup work was the formal FA5–FA1 alignment documented in D33.1. That deliverable describes a collaborative and iterative process involving bilateral meetings, workshops and continuous information exchange between the two Flagship Areas. For Demo Group 1, this alignment was especially relevant for YCS and Yard-CMS. The planning work clarified which developments from FA1 would be showcased within FA5 and how FA5 operational requirements should be fed back into FA1 developments. In practical terms, this meant aligning technical interfaces, agreeing on data exchange principles and defining how the Malmö–Alnabru demonstration would be used as a proof point for broader seamless corridor operations.

The demonstration setup was also shaped by the work package structure behind the technical enablers. According to the project's internal mapping, Demo Group 1 brings together developments linked to seamless planning, dynamic dispatching, monitoring and prediction, and seamless data availability/exchange. This includes, among others, Yard-CMS, YCS, ETA/ETD-related functions, TAO/YDS and real-time checkpoint data. WP24's role was not to develop these systems itself, but to ensure that their demonstration could be carried out in a coordinated way, with clearly identified demonstration sites, partner responsibilities and interaction points. In this sense, Task

24.1 served as the organisational layer that allowed the technical developments to be combined into one coherent demonstrator instead of several isolated pilots.

From a timeline perspective, the setup can be understood in three main phases. First, the specification phase established the use cases and the need for integrated capacity planning in the Malmö–Alnabru context. Second, the alignment and development phase translated these needs into system-specific developments and FA1–FA5 coordination activities, as reflected in D33.1. Third, the demonstration preparation and execution phase consolidated the relevant systems, sites and partner roles into the demonstrator described in D33.2. This progression from requirements to alignment and finally to showcase execution is consistent with the overall “funnelling” logic described in D24.1 and D33.2, where individual use cases are gradually bundled into operationally meaningful demonstration groups.

In terms of concrete setup, the demonstration involved the Malmö and Gothenburg area on the Swedish side and Alnabru on the Norwegian side, with data exchange and coordination across yard, terminal and mainline perspectives. Trafikverket provided checkpoint-related data capture, including IVG-based information. RISE supported the YCS and RailwayCDM-related data handling. Hacon contributed Yard-CMS and rail freight prediction-related functions. KTH contributed ETD prediction functionality. SINTEF contributed track assignment and dispatching functions relevant to Alnabru. Through WP24, these contributions were aligned into one demonstrator narrative centred on integrated capacity planning, dynamic capacity management and better operational response through shared data.

The expected output of Demo Group 1, as later reflected in D33.2, was not merely the technical operation of each individual system, but evidence that coordinated data exchange creates operational value. In particular, the demonstrator was prepared to show that linking last-mile, yard and mainline information flows allows later actors in the chain to react earlier to deviations, re-allocate resources more efficiently and reduce unnecessary delay propagation. WP24 therefore treated Demo Group 1 as an important showcase for how preparation, alignment and governance are prerequisites for making seamless corridor concepts demonstrable under realistic cross-border conditions.

5.2.3 Data needs & preparation

The implementation of the Seamless data-sharing and planning concepts is expected to generate measurable improvements across the rail freight transport chain, particularly in terms of operational efficiency, reliability, and resource utilisation.

A key benefit lies in the enhanced availability and quality of data across system boundaries. By enabling close to real-time exchange of harmonised data between Infrastructure Managers (IMs), Railway Undertakings (RUs), terminal operators and other

stakeholders, the solutions developed in TRANS4M-R support improved situational awareness and decision-making. This is particularly relevant for cross-border operations, where fragmented data landscapes have historically led to inefficiencies and delays.

The integration of prediction services, such as ETA and ETD calculations, further strengthens operational planning. These services allow stakeholders to anticipate disruptions and adjust plans dynamically, thereby reducing buffer times and increasing asset utilisation. In yard and terminal environments, this translates into improved sequencing of operations, reduced idle times, and more efficient handling of rolling stock and intermodal units.

In addition, the introduction of harmonised data exchange mechanisms contributes to a reduction of manual interventions and redundant data processing. This not only lowers operational costs but also decreases the likelihood of errors, thereby improving overall system robustness.

From a network perspective, the improved coordination between planning systems and operational systems enables better synchronisation of train paths, terminal slots, and last-mile operations. This supports a more integrated end-to-end planning approach, which is essential for achieving seamless multimodal transport.

Finally, the adoption of data space principles, including secure and sovereign data sharing, fosters trust between stakeholders and creates the foundation for scalable collaboration beyond the project scope. This is a critical prerequisite for the long-term digital transformation of European rail freight.

The Demo Group 1 requires comprehensive integration of multiple data and data domains to support integrated capacity planning across last-mile, yard, and main-haul operations.

Yard Operations Data: The Yard Capacity Management System (Yard-CMS) and Yard Coordination System (YCS) require detailed data on container positions, wagon locations, yard slot availability, and equipment status. According to D25.1 (Section 4.2), this includes real-time updates on yard congestion levels, transshipment progress, and stacking configurations. The Intelligent Video Gate (IVG) provide automated capture of wagon identity, wagon sequence, and dangerous goods information through RFID and computer vision technologies.

Checkpoint and Monitoring Data: checkpoint data from IVGs and RFID readers along the corridor provides continuous visibility of train movements and composition changes. D29.2 specifies checkpoint systems which can capture identification data, condition-related indicators, and event-based information with sub-second latency for real-time operational use.

Prediction and Planning Data: Prediction and Planning Data: The multimodal prediction services require historical data on train running times, dwell times at intermediate stops, and delay propagation patterns. The optimum data volume requirements include at least 24 months of historical operational data for model training, with real-time ingestion of position updates at around 1-minute intervals during train movements. The TAO (Track Assignment Optimizer) and YDS (Yard Dispatching System) tools developed by SINTEF require input data on track capacity, routing constraints, and dispatching priorities.

Data Quality and Harmonisation: D29.2 defines the data quality framework requiring 99.5% data availability and validation mechanisms for detecting anomalies in checkpoint readings and position reports.

Cross-Border Data Exchange: For the Malmö-Alnabru cross-border corridor, data exchange mechanisms must support both Swedish and Norwegian operational systems. D25.1 specifies alignment with TAF TSI data models for train master data, wagon master data, and movement data.

Data Governance and Access Control: Role-based access control mechanisms ensure that commercially sensitive data (e.g., customer information, specific cargo details) is protected while operational data is shared freely among authorized stakeholders. D25.2 and D32.1 define the data sovereignty principles where each participant maintains control over their data while enabling controlled sharing through the federated dataspace.

5.2.4 Limitations and need for standardisation

Despite the demonstrated potential of the developed solutions, several limitations and challenges have been identified during the preparation and execution of the demonstrations.

One major challenge relates to data availability and quality. While concepts for harmonised data sharing structure have been covered in the project, the actual availability of high-quality, consistent data across stakeholders remains uneven. Differences in system maturity, data governance practices, and technical capabilities continue to limit the full exploitation of data-driven services.

Another key limitation concerns the integration of legacy systems. Many stakeholders operate established IT systems that are not easily adaptable to new data exchange paradigms. The implementation of standardized interfaces and connectors therefore requires additional effort, both technically and organisationally. This can slow down onboarding processes and limit scalability in the short term.

Operational constraints also played a role during the demonstrations. In particular, the deployment of physical infrastructure such as European Railway Checkpoints and sensor systems was subject to delays and site-specific limitations. As a result, some use cases could only be validated partially or under controlled conditions.

From an organisational perspective, aligning multiple stakeholders with different priorities, business models, and regulatory environments remains a complex task. The introduction of data-sharing agreements and governance frameworks is essential but requires significant coordination effort and mutual trust.

Furthermore, while prediction models have shown promising results, their performance is highly dependent on data completeness and quality. Inconsistent or missing input data can reduce prediction accuracy and limit the operational value of such services.

Key lessons learned include the importance of:

- early alignment on data governance and sharing principles,
- incremental onboarding of stakeholders and systems,
- ensuring minimum data quality standards before deploying advanced services,
- and combining technical solutions with organisational and contractual frameworks.

The concept fits very closely with the direction of the proposed new European rail capacity regulation, especially the shift toward digital, coordinated, and rolling planning processes. It creates the framework and obligations that make this demo case scalable and standard rather than only experimental. The demo relies on early detection of deviations and dynamic replanning and on fast, structured data exchange across stakeholders. The Regulation pushes for standardised data exchange formats and digital capacity management systems. In this context, as each actor often describes the same reality differently, shared definitions shall be integrated into the ERA ontology such as train ID, train path, train composition, events and resources (tracks, yards, terminal slots). Even with common data models, systems must talk to each other reliably and the development of open APIs for train running data, capacity updates and event notifications should be encouraged so that for example a yard system in Sweden can connect easily to an IM system in Norway. In conclusion, there is a need for a strong coordination from ERA and the EU JU Rail to align research, EU Regulations and ERA activities (ontology, TSI Telematics).

Overall, the demonstrations confirm that while the technical foundations for seamless data exchange and planning are largely in place, further efforts are required to address organisational, regulatory, and data-related challenges to enable large-scale deployment.

5.3 Demo Group 2 – Integrated Cross-border Short-Term Planning and Dispatching

5.3.1 Scope

Demo Group 2 focuses on integrated cross-border short-term planning and dispatching, addressing the operational layer where planned rail freight operations are continuously adjusted in response to real-time conditions. The objective of this demonstration group is to show how harmonised data exchange and coordinated decision-making can improve

the management of resources and operations across national borders and organisational boundaries.

The central problem addressed is the fragmentation between planning systems and operational control systems, particularly in short-term time horizons. While long-term planning defines train paths and resource allocation, operational reality is shaped by disturbances such as delays, infrastructure constraints, rolling stock availability or terminal congestion. Demo Group 2 therefore aims to demonstrate how these deviations can be managed more effectively through integrated tools and shared information.

The storyline of the demonstration is based on the concept that short-term operational decisions must be taken collaboratively and supported by consistent, real-time information across stakeholders. Instead of isolated decision-making by individual actors, the demonstration promotes a coordinated approach where Infrastructure Managers, Railway Undertakings and terminal operators can react to changes based on a shared situational picture.

From a functional perspective, Demo Group 2 brings together capabilities related to:

- dynamic dispatching and traffic management, including reallocation of train paths and conflict resolution,
- short-term resource planning, covering locomotives, staff and terminal handling capacities,
- integration of prediction services, such as updated ETA/ETD values,
- and synchronisation of planning and execution systems, ensuring that operational changes are reflected consistently across all involved systems.

These functionalities are supported by technical enablers developed in WP26–WP32, particularly in the areas of seamless planning, dynamic dispatching, monitoring and prediction. The demonstration therefore highlights how these enablers can be combined to support more resilient and responsive rail freight operations.

The scope of Demo Group 2 is inherently cross-border, reflecting the need to coordinate operations across different national infrastructures and regulatory environments. It also builds on the same corridor-oriented logic as Demo Group 1, but focuses on operational decision-making rather than capacity planning, thereby complementing the overall Seamless Operations cluster.

5.3.2 Demonstration setup

Under Task 24.1, WP24 prepared Demo Group 2 by establishing a coordinated framework for aligning the relevant technical enablers, partners and demonstration scenarios related to short-term planning and dispatching.

The preparation followed the same structured approach applied across all demonstration groups. Starting from use-case definitions in WP24 and WP25, the project identified the

specific operational challenges related to cross-border dispatching and resource coordination. These were then translated into a set of interacting technical components developed across WP26–WP32.

A key aspect of the setup was the alignment between planning systems and operational control systems, ensuring that updates in one system can be propagated to others in a consistent and timely manner. This required defining clear interaction points between systems such as Train Planning Systems (TPS), Traffic Management Systems (TMS), Yard systems and terminal management solutions.

The Demonstration Execution Plan served as the central coordination tool, capturing:

- participating partners and their roles,
- involved systems and technical enablers,
- demonstration sites and operational contexts,
- and dependencies between developments.

In addition, the setup work involved close coordination with FA1 activities, particularly in areas related to traffic management and data exchange. This ensured that the demonstration reflects not only FA5-specific developments but also their integration into a broader European rail system context.

From a timeline perspective, the preparation evolved from:

1. specification of short-term planning use cases,
2. alignment of technical developments and interfaces,
3. to integration into a coherent demonstration scenario.

Through this process, WP24 ensured that Demo Group 2 could move from isolated system developments to a coordinated operational demonstration, highlighting the benefits of integrated short-term planning and dispatching.

5.3.3 Data needs & preparation

The successful implementation of Demo Group 2 relies on the availability of timely, consistent and interoperable operational data across all involved stakeholders.

Key data categories required for the demonstration include:

- train-related data, such as planned and actual train paths, delays and train composition,
- infrastructure data, including capacity constraints, temporary restrictions and network status,
- resource data, covering locomotives, staff availability and terminal capacities,
- and event and status data, reflecting real-time operational changes.

WP24 ensured that these data requirements were clearly defined and aligned with the Conceptual Data Model (CDM) developed within the project. This alignment is essential to enable consistent interpretation of data across different systems and organisations.

A central aspect of data preparation was the harmonisation of heterogeneous data sources. Given the diversity of systems used by IMs, RUs and terminal operators, data often exist in different formats and levels of granularity. WP24 therefore supported the definition of mapping and transformation processes to ensure compatibility with the internal data models of the demonstrator systems.

In addition, the preparation included:

- establishing data provision agreements between partners,
- defining data access and sharing rules, including alignment with federated data space concepts,
- and ensuring minimum data quality requirements for demonstration purposes.

Where relevant, the prepared data were also made compatible with the data exchange mechanisms developed in WP32, enabling their use within a broader data-sharing ecosystem.

Overall, Task 24.2 ensured that Demo Group 2 was supported by a reliable data foundation, enabling the demonstration of integrated short-term planning and dispatching under realistic operational conditions. For the extended data requirements and federated data space concepts we refer to D25.1, D29.2 and 32.1.

Real-time Traffic Management Data: The short-term planning and dispatching functionality requires continuous ingestion of real-time traffic data including actual train positions, speed profiles, signal states, and infrastructure availability. Traffic management systems must receive position updates at 30-second intervals during active train movements, with event-triggered updates for critical occurrences such as unscheduled stops, delays exceeding 5 minutes, or infrastructure incidents.

Dynamic Resource Allocation Data: Short-term dispatching decisions depend on real-time visibility of resource availability including locomotive assignments, crew schedules, and terminal handling capacity. D25.1 and D32.1 details the data structures for resource master data, including locomotive technical specifications, crew qualification records, and terminal equipment status. The dynamic resource planning tools require integration with HR systems for crew availability and maintenance systems for locomotive readiness.

Conflict Detection and Resolution Data: The dispatching systems require data on train priority classes, path conflicts, and resolution preferences. The conflict detection algorithms analyze train path overlaps, resource contention, and timing conflicts. Resolution data includes pre-defined priority rules, alternative routing options, and

negotiation parameters for collaborative decision-making between multiple Infrastructure Managers. This was recorded in D29.2 and D32.2.

Cross-border Coordination Data: For cross-border operations, the demonstration requires harmonised data exchange between Traffic Management Systems (TMS). In Demo Group 2 the interface requirements for border handover procedures, including advance notification of train readiness, border crossing times, and handover confirmations were specified. The data exchange follows TAF TSI templates for cross-border train master data and movement messages, as recorded in D25.1, D31.4, D32.1 and D32.2.

Prediction Services Integration: Updated ETA/ETD values generated by prediction services has been integrated into the short-term planning. Prediction updates should be triggered by significant events (delay, route changes) and provided at 5-minute granularity for the next 4 hours, with hourly forecasts extending to 24 hours, as described by Demo Group 2 in D25.1, D32.1 and D31.4. The prediction models consume real-time position data, historical running time patterns, and infrastructure availability.

Data Exchange Mechanisms: The WP32 data exchange mechanisms enable seamless communication between planning and dispatching systems. Demo Group 2 specifies in D25.1 the microservices-based architecture *Deplide* with event-driven synchronization for real-time messages. API gateways provide standardized REST interfaces for system-to-system communication with rate limiting and monitoring capabilities.

Federated Data Space for Dispatching: The federated dataspace enables controlled data sharing between cross-border stakeholders while maintaining data sovereignty. EDC connectors facilitate secure data exchange between national TMS systems with encryption, authentication, and audit logging. The federated catalog enables discovery of available data services across organizational boundaries.

Data Quality Monitoring: Continuous monitoring of data quality is essential for reliable dispatching decisions. Demo Group 2 defines data quality metrics including completeness (minimum 99% field population), accuracy (position accuracy within 50 meters), timeliness (maximum 1-minute latency), and consistency (cross-system validation). Automated alerts trigger when data quality falls below thresholds (specified in D29.2, D25.1 and D32.1).

5.3.4 Limitations and needs for standardisation

Demo Group 2 provides relevant input to standardisation activities, particularly in the areas of real-time data exchange, short-term planning processes and cross-system interoperability.

One key aspect concerns the extension and practical application of existing railway regulations and data standard messaging, such as TAF TSI and the new TSI Telematics. While these standards provide a foundation for data exchange in rail freight, the demonstration highlights the need for enhanced support of real-time operational data

and short-term planning processes. The new TSI Telematics is the baseline of cross-border interoperability layer the demo builds on as the Regulation defines standard message structures, shared identifiers and core business processes. However, the TSI Telematics is based on event approach that is not real-time enough. While the TSI messages are often periodic or triggered at defined milestones, this demo case needs real-time operational updates and fast propagation of deviations across systems. TSI processes are largely built around pre-arranged paths and (semi)-static planning whereas the demo requires continuous updates of ETA/ETD, capacity availability and operational constraints. The TSI Telematics should be further enhanced for frequent replanning cycles and dynamic capacity reallocation as planned in the new Capacity Regulation.

In addition, the demonstration contributes to the development and validation of:

- common data models, such as the Conceptual Data Model (CDM),
- standardised interfaces and APIs for system-to-system communication,
- and data exchange mechanisms aligned with federated data space principles.

Through the practical implementation of these concepts, Demo Group 2 provides evidence on how existing standards can be extended or complemented to support more dynamic and integrated operations.

Another important aspect is the alignment with broader European initiatives, including:

- the System Pillar activities of Europe's Rail,
- the Joint Sector Group,
- and data-sharing frameworks such as the European Rail Data Space (ERDS).

The findings from Demo Group 2 are therefore expected to contribute to:

- identifying gaps in current standards,
- proposing extensions or refinements,
- and supporting the evolution of interoperability frameworks for rail freight.

Overall, Task 24.3 ensures that the insights gained from the demonstration are not limited to project-specific implementations but are translated into standardisation-relevant contributions, supporting the long-term objective of seamless and interoperable European rail freight operations.

The successful implementation of Demo Group 2 is contingent on a range of interrelated technical, organisational and data-related dependencies, reflecting the inherently integrated nature of short-term planning and dispatching in a cross-border rail freight context.

From a technical perspective, the demonstration depends on the availability and maturity of several key technical enablers developed across WP26–WP32. In particular, functionalities related to dynamic dispatching, traffic management and prediction services must be sufficiently advanced and interoperable to allow coordinated decision-

making across systems. The ability to exchange information between Train Planning Systems, Traffic Management Systems and other operational tools in near real-time is a prerequisite for demonstrating the intended benefits of integrated short-term planning.

At the organisational level, the demonstration relies on effective coordination between multiple stakeholders, including Infrastructure Managers, Railway Undertakings and terminal operators. Given the cross-border nature of the use case, this also requires alignment of operational procedures and decision-making processes across different national and organisational contexts. The establishment of clear roles, responsibilities and communication channels is therefore essential to ensure that operational decisions can be taken in a coordinated manner.

Data-related dependencies play a particularly critical role. The demonstration requires the availability of high-quality, timely and consistent operational data, including real-time updates on train movements, infrastructure status and resource availability. Any limitations in data completeness, accuracy or accessibility can directly affect the performance of prediction models and dispatching decisions, thereby reducing the overall effectiveness of the demonstration.

In addition, Demo Group 2 is closely interconnected with other demonstration groups and work packages within the project. It builds on data inputs and planning concepts developed in Demo Group 1 and benefits from real-time monitoring capabilities demonstrated in Demo Group 3. At the same time, it forms an integral part of the WP33 showcase, where the combined functionality of multiple technical enablers is validated in an operational setting. These interdependencies underline that the value of Demo Group 2 emerges not from isolated components, but from the coordinated interaction of systems, data and stakeholders across the Seamless Freight ecosystem.

5.4 Demo Group 3 - Standardised European Railway Checkpoints

5.4.1 Scope

Demo Group 3 focuses on the development and demonstration of standardised European Railway Checkpoints (ERCs) as a key enabler for real-time monitoring, inspection and data generation along the rail freight network.

The objective of this demonstration group is to show how automated, wayside and on-board sensing technologies, combined with harmonised data models and interfaces, can provide consistent and high-quality operational data across different locations and national infrastructures. These checkpoints act as digital observation points within the rail system, capturing information on train composition, wagon condition, load status and operational events.

The underlying problem addressed is the limited availability and heterogeneity of operational and condition-related data in current rail freight operations. Today, inspection processes are often manual, fragmented and not standardised across borders,

leading to inefficiencies, delays and limited data usability. Demo Group 3 therefore aims to demonstrate how standardised checkpoint solutions can replace or complement these processes with automated, scalable and interoperable alternatives.

The scope includes multiple implementation environments, such as yards, terminals, mainline sections and border crossings, reflecting the different operational contexts in which checkpoints can provide value. The demonstration integrates technologies such as Intelligent Video Gates (IVGs), RFID systems and on-board sensors, which together enable both static and dynamic data capture.

In this context, Demo Group 3 contributes to the overall Seamless Operations vision by providing a continuous and standardised data layer, which can be used by planning, dispatching and monitoring systems developed in other demonstration groups. It therefore plays a foundational role in enabling data-driven decision-making across the rail freight ecosystem. The demo group is not just using standards but helps to define them. This should be integrated in the ERA ontology.

5.4.2 Demonstration setup & alignment

The demonstration setup for Demo Group 3 was designed as a distributed and multi-site implementation, reflecting the diverse operational environments in which European Railway Checkpoints are expected to operate. Installations and testing activities were carried out across several countries, including Germany, Sweden, Spain and the Netherlands, each representing specific use cases and thus different modules such as mainline monitoring, terminal operations and yard processes. This distributed setup allows for a comprehensive assessment of checkpoint performance under varying infrastructural and operational conditions (Kordnejad et al. 2024).

The preparation activities under Task 24.1 focused on ensuring a coherent demonstration framework across these sites. This required aligning technical implementations based on the common specifications developed in WP29, while still allowing for necessary adaptations to local conditions. As a result, comparable checkpoint functionalities could be deployed across different locations, despite differences in infrastructure, operational procedures and available data sources. To coordinate the content, a number of workshops were conducted, during which KPIs were jointly developed, some common to all sites and others specific to individual sites and dependent on the module. These were then validated at the respective sites.

Our common KPIs (suggestions)

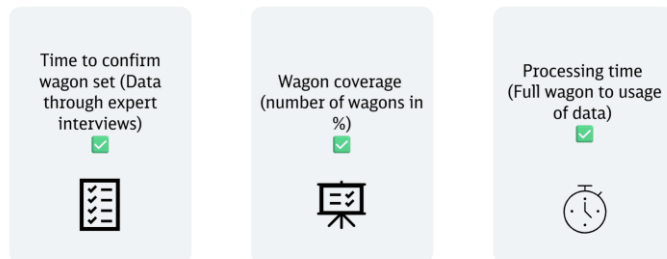


Figure 4 Base of the KPI workshop for ERC

A key aspect of the setup was the definition of harmonised use cases and evaluation approaches, enabling the results obtained at different sites to be analysed within a common framework and have been designed as modules. Each module served a specific purpose. These modules can be used for various applications, but they can also be combined. This includes, for instance, the automated identification of rolling stock and intermodal units, the detection of relevant operational events, and the monitoring of wagon condition. The selection of these use cases was guided by observed operational needs at critical stopping points such as borders, terminals, and marshalling yards. The primary goals were to improve efficiency, ensure safety, and promote harmonisation across the European railway network. Technical solutions leverage robust AI models capable of detection and recognition under various conditions, with scalability for future expansion. Additionally, harmonisation and alignment with other EU Rail initiatives were pursued to guarantee standardisation and interoperability of diagnostic data and operational procedures (Kordnejad et al. 2024). The demonstration execution plan further coordinated the roles of participating partners, the deployment timelines and the interaction between checkpoint systems and other technical enablers within the project (Kordnejad et al. 2026).

Table 1 Distribution of the modules for ERC (Kordnejad et al. 2026).

Module focus	Lead partner
AI-powered condition monitoring	DB Cargo
Checkpoints for improving sharing of logistics information	Trafikverket
Checkpoints deployment in Can Tunis for capturing yard movements	Adif
Recognition of Hazardous Materials Plates/Placards and UIC Code	ProRail

Particular attention was given to the integration of checkpoint systems into the broader Seamless Freight architecture. Rather than acting as isolated inspection tools, the checkpoints are positioned as data providers that feed into planning, monitoring and decision-support systems developed in other work packages. This integration is essential to demonstrate the added value of standardised checkpoints at system level, beyond their standalone functionalities. The first step towards achieving this was taken by sharing data between companies and countries. This should already have been demonstrated in the demo. The entire presentation was to be shown to the public in an online webinar.

5.4.3 Data needs & preparation

The implementation of Demo Group 3 is fundamentally centred around the generation and utilisation of data, as the primary function of railway checkpoints is to capture first operational and condition-related information. Afterwards to process them in an automated manner. The data produced by checkpoint systems spans multiple domains, including identification of rolling stock and loading units, monitoring of wagon condition, and detection of operational events such as train movements and composition changes (Kordnejad et al. 2024).

Within Task 24.2, particular emphasis was placed on ensuring that this data can be used in a consistent and interoperable way across different systems and stakeholders. One of the main challenges in this context is the heterogeneity of data sources, as checkpoint systems rely on a combination of sensing technologies such as cameras, RFID and on-board devices. These technologies generate data in different formats and with varying levels of granularity, requiring harmonisation before it can be effectively integrated.

To resolve this heterogeneity, the Spanish use case in Demo Group 3 utilised Conceptual Data Model (CDM) - a structured methodological workflow developed in collaboration with FP1-MOTIONAL. This process involved mapping raw sensor outputs (e.g., Intelligent Video Gate images and RFID reads) to standardised data objects within the Conceptual Data Model (CDM). By isolating domain objects such as Train Run, Wagon, and Load Unit, the checkpoints shifted from being isolated 'image-capturers' to becoming interoperable data providers. A transformation layer was implemented to convert proprietary JSON outputs into CDM-compliant payloads, ensuring that every observation retains a reversible trace (provenance) to its source sensor.

This ensures consistent interpretation across systems and the mapping from raw sensor outputs to CDM-compliant data objects (e.g. standardisation of wagon identification formats, condition indicator codes, and event classification schemes). This includes the structuring of identification data, condition-related indicators and event-based information, as well as the mapping of raw sensor outputs to higher-level data objects that can be consumed by other systems.

```
{
  "wagon_number": "378049930613",
  "timestamp": "2025-08-01T00:00:32.000Z",
  "location": "urn:epc:id:sgln:7332862.00211.1",
  "train_id": "0080202508010456",
  "vehicle_position": 1,
  "wagon_side": "left",
  "view": "bogie",
  "img_url": "https://.../20250801000017_1337.jpg",
  "damages": [
    {
      "error_code": "3.2.2",
      "source": "ai",
      "confidence": 0.86,
      "bounding_box": { "x_min": 1053, "y_min": 532, "width": 323, "height": 254 }
    },
    {
      "error_code": "2.1.5",
      "source": "human",
      "bounding_box": { "x_min": 1400, "y_min": 600, "width": 440, "height": 376 }
    }
  ],
  "un_numbers": [
    "1088",
    "1089",
    "1090",
    "1091"
  ],
  "loading_units": [
    "BICU1234567",
    "BICU1234568"
  ]
}
```

Figure 5 JSON example – data exchange of a wagon (Kordnejad et al. 2026).

In addition to that the German and Swedish partners collaborated and used a minimal version of this CDM which was demonstrated live in the webinar for D29.2 to show how data from different checkpoints can be combined and visualised in a sample system. Further details on how these were structured and used, were presented in the deliverables D29.2 (Kordnejad et al., 2026) and D32.1 (Bertilsson et al., 2026). To reduce bandwidth requirements and enable real-time responses, standardised European checkpoint systems have to be high performant. Edge computing proposed by Demo Group 3 and described in D29.2 allows to process raw sensor data locally, transmitting only relevant results to central systems.

In addition to structural harmonisation, data preparation activities also addressed aspects such as data quality, filtering and validation. The reliability of checkpoint outputs is particularly important given their intended use in operational decision-making, and therefore mechanisms were established to ensure that the generated data meets defined quality criteria (Kordnejad et al. 2026). At the same time, data sharing arrangements were put in place to enable the exchange of checkpoint data between stakeholders and systems, taking into account data governance considerations such as ownership, access rights and confidentiality.

Through these activities, Task 24.2 ensures that the data generated within Demo Group 3 is not only technically available, but also usable and meaningful within the wider context of the Seamless Freight ecosystem.

The checkpoint systems integrate multiple sensing technologies including Intelligent Video Gates (IVGs), RFID readers, and on-board sensors. IVGs specified by Demo Group 3 capture high-resolution images for computer vision-based wagon identification, while RFID systems provide unique wagon identifiers with read ranges up to 10 meters. On-board sensors transmit wagon condition data including temperature, vibration, and door status .

Automated train composition detection provides real-time information on wagon sequence, wagon types, and load status. Standardised checkpoint systems must achieve high accuracy in wagon identification and sequence detection. The data includes empty/full status, dangerous goods classification, and intermodal loading unit (ILU) identification for containers and swap bodies, as recorded in D29.2.

5.4.4 Limitations and needs for standardisation

Demo Group 3 provides a strong contribution to standardisation by addressing the need for harmonised approaches to data acquisition and processing in rail freight operations. The concept of European Railway Checkpoints inherently requires a level of standardisation to ensure that systems deployed in different countries and operational contexts can produce comparable and interoperable results.

Demo Group 3 can improve ETA/ETD quite significantly only if the ERCs (European Railway Checkpoints) are not just “data collectors,” but also trusted, standardised truth points that continuously recalibrate the plan. With ERCs, every checkpoint becomes a high-quality timestamped observation with actual passing time, train integrity confirmation and updated composition and condition. As for the other demo groups, standard definitions and semantics are needed in terms of train identity, wagons ID, timestamps, locations, events...

A central element in this regard is the definition of common technical and functional specifications for checkpoint systems. These specifications cover both the physical configuration of the systems, such as sensor setups and installation requirements, and the logical aspects, including data structures, interfaces and processing workflows. By implementing these specifications across multiple demonstration sites, the project is able to validate their applicability and identify potential gaps or areas for refinement. And yet, there are different local conditions and use cases. For this reason, the use cases mentioned in D29.1 were distributed across various countries. This enabled several scenarios to be tested in parallel, resulting in the modules mentioned above. These will

enable various configurations and combinations of technologies to be utilised in the future, depending on the specific use case (Kordnejad et al., 2026).

The demonstration also highlights the increasing role of automated and AI-based inspection methods, which introduce new challenges for standardisation. In particular, aspects such as the quality and reliability of sensor data, the validation of AI-generated outputs and the consistent interpretation of detected conditions require further harmonisation. The findings from Demo Group 3 therefore provide valuable input for the development of future standards in these areas.

There are still significant gaps in the standardisation of AI-generated outputs, even though Wave 1 of the CDM implementation covered about 70% of stated requirements, concentrating on high-priority assets like waggon and ILU identification. Although the current TRL 6/7 has been achieved all over the partners in WP 29 the transition to a full, commercially ready TRL 8/9 will be the focus of the Second Wave. The next development will concentrate on ontologies to handle time-varying property values and data reconciliation.

Furthermore, the work supports alignment with existing European frameworks, including TAF TSI and the new TSI telematics and emerging initiatives related to data sharing and digitalisation in rail. By ensuring that checkpoint-generated reliable operational data can be integrated into these frameworks, the project contributes to the creation of a more coherent and interoperable digital ecosystem for rail freight.

Overall, Task 24.3 demonstrates that standardisation is not only a technical requirement, but also a key enabler for scaling checkpoint solutions across Europe and unlocking their full potential within the rail freight system.

5.5 Demo Group 4 – Multimodal Integration

5.5.1 Scope

Demo Group 4 addresses the integration of rail freight into multimodal transport chains by focusing on the digital accessibility, planning and booking of intermodal services. The demonstration aims to show how different systems and platforms can be combined to provide a seamless user experience across the full transport chain, from initial search to booking and, where necessary, the creation of new transport services.

The underlying challenge is the fragmentation of today's logistics landscape, where information about available transport options is distributed across multiple systems and stakeholders. This fragmentation makes it difficult for customers to identify suitable rail-based transport solutions and to combine services from different providers into a coherent transport chain. As a result, rail is often perceived as complex and less accessible compared to other modes.

Demo Group 4 therefore focuses on demonstrating how this complexity can be reduced through digital integration. The concept builds on the idea of a “one system” approach, in which multiple platforms interact and exchange data to provide a unified view on available transport options and enable coordinated booking and management processes.

The scope of the demonstration includes three closely linked functional areas: the identification of suitable multimodal transport options, the booking and management of these services, and the ability to generate new transport solutions where existing services are insufficient. These elements are not treated as isolated functionalities, but as part of a continuous process that reflects the real-world needs of logistics service providers, shippers and railway undertakings.

5.5.2 Demonstration setup & alignment

The demonstration setup for Demo Group 4 is based on the coordinated development and integration of multiple digital platforms that together represent the multimodal transport chain. Rather than implementing a single monolithic system, the approach reflects the reality of the market, where different actors operate their own systems with specific functionalities and interfaces.

The preparation activities therefore focused on defining how these systems can interact in a structured and interoperable manner. This includes aligning the functionalities of transport planning tools, booking platforms and resource management systems, as well as defining the interfaces through which they exchange information. The demonstration setup follows the sequence of the three main use cases, ensuring that outputs from one stage can be used as inputs for the next.

A central element of the setup is the integration of data flows between systems. As illustrated in the WP31 concept, a consistent set of core data elements, such as origin and destination, train identifiers and capacity information, must be exchanged across platforms to enable a seamless process. Ensuring the availability and consistency of this data across different systems is therefore a key prerequisite for the demonstration.

In addition, the setup required close coordination between participating stakeholders, including logistics service providers, railway undertakings and infrastructure managers. Their systems and processes needed to be aligned to ensure that the demonstrated workflows reflect realistic operational conditions. This includes not only technical integration, but also agreement on roles, responsibilities and data provision.

The Demonstration Execution Plan ensures that the different components are implemented in a coordinated manner and that their interaction can be validated in an end-to-end scenario. The focus is thereby not only on individual system functionalities, but on the overall user experience and the ability to move seamlessly from planning to execution within a multimodal context.

5.5.3 Data needs & preparation

The effectiveness of multimodal integration is highly dependent on the availability and quality of data, as the demonstrated functionalities rely on combining information from multiple sources into a coherent and usable format. In the context of Demo Group 4, this includes timetable data, capacity information, booking data and operational updates from different service providers.

A key challenge addressed in Task 24.2 is the integration of heterogeneous data sources. Different operators and systems provide data in varying formats, with different levels of detail and update frequencies. This can lead to inconsistencies, for example between commercial and operational timetables or between planned and actual capacity availability.

To address these challenges, mechanisms for data harmonisation and validation are required. The demonstration therefore includes approaches for consolidating data from multiple sources, resolving contradictions and ensuring that the resulting information is suitable for use in planning and booking processes. This includes the application of plausibility checks and the use of integration layers that combine and standardise incoming data.

In addition, the use of common or emerging standards, such as EDIGES and TAF TSI, plays an important role in facilitating data exchange between systems. These standards provide a basis for defining consistent data structures and interfaces, while still allowing for flexibility in how individual systems process and use the data.

Data governance is another important aspect, as the willingness of stakeholders to share data depends on clear rules regarding access and usage. The demonstration therefore considers mechanisms for controlled data sharing, including the possibility to restrict visibility of certain information based on user roles or commercial relationships. This is particularly relevant in a competitive environment where operators may not want to disclose all information to all parties.

Through these activities, Task 24.2 ensures that the data required for multimodal integration is not only technically available, but also consistent, reliable and usable across system boundaries.

The demonstration requires integration of timetable data from multiple rail operators and transport modes. Timetable data must include departure/arrival times, platform information, transit times, and frequency details.

Capacity data must be updated regularly and include both quantitative (number of slots) and qualitative (equipment type, service level) information. Demo Group 4 set data structures for terminal capacity (slot availability, handling capacity), rail path capacity (available train paths, booking windows), and transshipment capacity (equipment availability, labour) in D25.1, D31.4 and D32.1. The system must support multi-leg

bookings combining rail, road, and potentially other modes into a single transport chain. Hence, multimodal pricing and services require integration of tariff data from multiple service providers. Booking data models are described in D31.4, D32.2 and include booking references, booking status, confirmation times, cancellation policies, modification rules including the transport leg details, service levels, and pricing information.

Moreover, detailed cargo information including origin, destination, weight, dimensions, commodity type, and special handling requirements (e.g., dangerous goods, temperature control) is required for multimodal planning. D25.2 specifies the cargo data schema aligned with EDIGES and TAF TSI standards. This data enables compatibility checks between cargo requirements and available services.

5.5.4 Limitations and needs for standardisation

Demo Group 4 contributes to standardisation by addressing the need for interoperable data exchange and coordinated system interaction in multimodal freight transport. The demonstration highlights that seamless integration cannot be achieved without a certain level of harmonisation in data models, interfaces and functional processes.

One important aspect is the alignment with existing European standards, in particular TAF TSI and the new TSI Telematics, which provides a foundation for data exchange in rail freight. At the same time, the demonstration explores the use of newer standards such as EDIGES, which aim to facilitate data interoperability between combined transport stakeholders. The interaction between these standards and their practical applicability in multimodal contexts is an important outcome of the demonstration.

Demo Group 4 lays the foundation for closing the open point of the TSI Telematics on the aspects relating to the interoperability of data sharing and associated systems for the reservation, payment and invoicing of freight rail transport services, including services based on intermodal oriented timetable integrating buffer times and milestones in multimodal freight terminals.

The work also highlights the need for standardised approaches to integrating data from multiple sources. This includes not only technical formats, but also the semantic alignment of data, ensuring that information provided by different systems can be correctly interpreted and combined. The demonstration provides insights into how such alignment can be achieved in practice and where further standardisation efforts are required.

In addition, Demo Group 4 identifies gaps related to cross-platform integration, particularly in areas such as booking processes, capacity information and the generation of new transport services. These aspects are not fully covered by existing standards and require further development to enable fully seamless multimodal workflows.

Overall, Task 24.3 shows that standardisation is a key enabler for scaling multimodal integration solutions. By providing practical validation of concepts and identifying

remaining challenges, Demo Group 4 contributes to the ongoing development of a harmonised digital ecosystem for European rail freight.

6 Conclusions

This deliverable has presented the work carried out within WP24 to prepare, structure and align the Seamless Freight demonstrations of FP5-TRANS4M-R. As defined in the Grant Agreement, the project aims to establish rail freight as a backbone of a resilient, low-emission European logistics system through interoperable, integrated and validated digital solutions. Within this context, WP24 fulfilled a central enabling role by ensuring that the technical developments of the Seamless cluster could be demonstrated in a coordinated, data-ready and standards-aligned manner.

The work performed in WP24 confirms that the successful demonstration of Seamless Freight functionalities requires more than the development of individual technical enablers. Instead, it depends on the structured alignment of use cases, data availability, system interoperability and organisational coordination across multiple stakeholders and countries. By applying a uniform analytical framework across all demonstration groups, WP24 ensured that these elements were consistently addressed, thereby creating a coherent foundation for the execution of WP33 and WP34.

A key outcome of this deliverable is the establishment of a clear link between technical development and operational validation. The demonstration groups defined and prepared within WP24 bundle individual use cases from WP26 to WP32 into integrated scenarios that reflect real operational processes along European freight corridors and multimodal chains. This approach enables the assessment of system interactions and dependencies, rather than isolated functionalities, and supports the generation of meaningful evidence with respect to performance improvements, data exchange and interoperability.

The demonstrators illustrate two points: Firstly: In most cases, there are many different stakeholders involved who exchange data in one way or another. Secondly: Constellations such as those found in the demonstrators also exist elsewhere on the rail network. There, different stakeholders find themselves in the same roles. At the system level, individual actors are therefore faced with the problem that they have to exchange data in different ways in more or less the same situations, as the constellation of actors is slightly different, even though the underlying transport task is the same. There is therefore a need for standardised data formatting and sharing, and above all for institutional agreements on how data sharing should take place. One way to solve this problem is through Dataspaces. Consideration was therefore given to the suitability of Dataspaces for the problems arising in the demonstrators. In doing so, particular attention was paid to the constellation of stakeholders and their roles. Furthermore, incentives were sought that would encourage individual stakeholders to participate in standardised data exchange. Obstacles to the introduction of Dataspaces were identified in D32.1.

The work on data management has highlighted the importance of accessible, high-quality and harmonised data as a prerequisite for all Seamless demonstrations. WP24 has therefore ensured that baseline datasets, data provision agreements and mappings to common data models are in place, enabling the involved systems to operate on a consistent information basis. At the same time, the work has confirmed that data availability and data sharing conditions remain one of the main challenges for scaling Seamless concepts beyond the project environment.

From a standardisation perspective, WP24 has identified and structured the key areas where the demonstrated concepts may impact existing frameworks. The alignment with standards such as TAF TSI and EDIGES, as well as the interaction with the System Pillar, ERA and related initiatives, ensures that the findings of the Seamless demonstrations can be transferred into the broader European railway system. In particular, the project provides input on data exchange, interoperability of digital systems and the integration of new functionalities such as automated inspection and multimodal service orchestration.

Overall, WP24 has provided the organisational, technical and methodological foundation required to move from concept development to coordinated demonstration. By preparing the demonstration groups in a structured and interoperable way, the work contributes directly to the validation of the Seamless Freight vision under realistic operational conditions. This, in turn, supports the long-term objective of establishing a harmonised, digital and interoperable rail freight system across Europe, as foreseen in the FP5-TRANS4M-R programme.

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