



D33.1

Integration of network management use case with Destination FA1

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1 Executive Summary

This deliverable reflects the objectives of WP33, where seamless corridor operations will be demonstrated and validated by integrating physical and information flows within Destination 5. The report is an output of Work Package 33 (WP33) within the Flagship Project 5 (FP5) – TRANS4M-R, specifically contributing to the "Showcase Seamless Corridor" objective.

The primary objective is to specify the integration of a **network management use case** with **Destination FA1**, designed to optimize operational efficiency and enhance supply chain management. The methodology for this deliverable was a collaborative and iterative process with partners from both FP1 MOTIONAL and FP5 TRANS4M-R.

The findings include the successful establishment of a comprehensive planning framework and the identification of distinct demonstration groups. Key developments from FP1, such as the **Conceptual Data Model (CDM)**, **European Rail Data Space (ERDS)**, **Yard Coordination System (YCS)** and the **Yard Capacity Management System (Yard-CMS)**, have been successfully assigned to these groups, ensuring their planned applications are well-defined.

The report acknowledges that the work is currently in the planning phase, and the outcomes are based on planned coordination and stakeholder commitments. The actual execution may reveal unforeseen challenges. The next steps include the execution of the demonstrations, followed by analysis of the results, which will be described in Deliverable 33.2 "Results on the Seamless Corridor" reporting on the demonstration activities, and in Deliverable 32.1 "Results from Demonstration" reporting on the data sharing concepts for specific use cases.

Keywords: Seamless Corridor, Network Management, Destination FA1, Destination FA5, Rail Freight, Showcase, Yard Coordination System, Yard Capacity Management System, Conceptual Data Model, European Rail Data Spaces.

2 Abbreviations & Acronyms

Abbreviation / Acronym	Description
API	Application Programming Interface
CA	Certification Authority
CDM	a) Conceptual Data Model b) Collaborative Decision Making
DSPs	Data Space Protocols
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
EVN	European Vehicle Numbering
FA	Flagship Area
FP	Flagship Project
IDSA	International Data Spaces Association
ILUs	Intermodal Loading Units
KPI	Key Performance Indicator
MAWP	Multi-Annual Work Plan
PCS	Path Coordination System
RailwayCDM	Railway Collaborative Decision Making
ScanMed	Scandinavian-Mediterranean Transport Corridor
TAF TSI	Telematics Applications for Freight Technical Specification for Interoperability in rail freight
TE	Technical Enablers
TPS	Train Planning System
Yard-CMS	Yard Capacity Management System
YCS	Yard Coordination System

3 Background

The present document constitutes the Deliverable D33.1 “Integration of network management use case with Destination FA1” in the framework of the Flagship Project 5 - TRANS4M-R as described in the EU-RAIL MAWP. The project aims to boost innovation for the European rail freight sector, by developing, validating and demonstrating Technical Enablers (TE) within FP5-TRANS4M-R.

This deliverable is a key component of work package 33 (WP33), Showcase Seamless Corridor. The objective of WP33 is to demonstrate and validate the concept of a seamless corridor operation within Destination 5, focusing on the comprehensive integration of both information flows and the physical handling of resources and goods. This is achieved through the application of enabling technologies in use cases designed to facilitate seamless operations. WP33 aims to unify these use cases derived from work packages within Seamless Operations into a cohesive and comprehensive corridor approach.

The Scandinavian-Mediterranean (ScanMed) Rail Freight Corridor serves as the primary base for the showcase. The solutions that are being developed and discussed in WP33 are intended to be transferable and applicable to other transport corridors, demonstrating their versatility and scalability.

One aspect, highlighted within the WP33, is the field of network management, aligned with the developments of the same topics in FP1, as described in this deliverable. To achieve the seamless integration necessary for efficient corridor operations within FP5, the developments within FP1 will be important to include in the corridor approach towards Seamless Operations.

Deliverable 33.1 specifically addresses the collaboration between FA5 and FA1 by focusing on the integration of network management use cases with FP1. This integration aims to optimize operational efficiency, enhancing supply chain management, and improving customer orientation within the corridor. Furthermore, it contributes directly to the validation and demonstration of key Technical Enablers (specifically TE 9,10, and 15) within relevant operational environment.

This particular output is not a standard, standalone result of Task 33.1. Instead, it is a key deliverable generated from the collaboration and interaction between two of our Flagship Areas. Consequently, the stakeholders for this specific output are the partners involved in the interaction between these two Flagship Areas.

The deliverable is structured as follows: Chapter 4 describes the objectives of this deliverable; Chapter 5 outlines the alignment methodology between FA1 and FA5, followed by an overview of the developments; Chapter 6 describes how the developments are planned to be showcased within the demonstrations of FA5; Chapter 7 contains the concluding remarks of this deliverable.

4 Objective/Aim

In WP33 a seamless transport corridor will be showcased integrating the physical flow and the information flow, where part of the ScanMed corridor serves as a base for the showcase, along with other corridors.

This deliverable reports the collaborative efforts and interactions between FP1 and FP5, which will be demonstrated in the upcoming project showcase phase.

The main objective of this deliverable 33.1 (D33.1) is to report on the interaction and integrations in FP1 (MOTIONAL) that are shown during the demonstrations in the Seamless Corridor in FP5 (TRANS4M-R). It focuses on the cooperation between FA1 and FA5 within the field of network management, the integration between the projects and the way that achievements made in FP1 will be demonstrated in FP5.

4.1 Task Description

The table below links the task described in the Grant Agreement with the related WP33 objectives of this deliverable that feature these elements.

	Task definition from GA (WP33)	Output of deliverable
Task 33.1	Planning for showcase	This deliverable constitutes the main output of this subtask, as defined in the GA. It describes the interactions and integrations of developments in FA1 (FP1 MOTIONAL) and how these relevant developments are planned to be showcased within FP5 TRANS4M-R.

5 Planning of Showcase

This chapter introduces the main stakeholders and key systems involved in Task 33.1 Planning of showcase, and the collaborative workflow that supports the strategic coordination between Flagship Area 1 (FA1) and Flagship Area 5 (FA5) for the Seamless Corridor Showcase. The developments from FA1 planned to be demonstrated in WP33 include the Yard Coordination System (YCS), Conceptual Data Model (CDM), European Rail Data Spaces (ERDS) and Yard Capacity Management System (Yard-CMS). This deliverable explains these system developments and how they connect to the developments in FA5.

5.1 Stakeholder alignment

Relevant stakeholders (in the scope of this deliverable), both within FA1 and FA5, consist of mainly infrastructure managers (such as Trafikverket and ADIF) involved in the projects, governmental agencies (Jernbanedirektoratet), railway undertakings (such as RENFE, CD Cargo and DB Cargo), as well as IT suppliers, research institutes and industry partners (such as RISE, LSP, SINTEF, HACON, CEIT and INDRA). Furthermore, experts from FP1 have been involved in the process of developing solutions, based on the requirements within FP5, to successfully integrate the functions and systems from FP1 into the Seamless Corridor demonstrations in FP5, WP33. The workflow of the alignments between the FPs was outlined in D25.1 and is described in more detail in the chapter below.

5.2 Alignment Methodology

The collaborative alignment between the flagship projects focuses on showcasing developments from FA1 within FA5 (e.g. the functionalities from the system YCS), as well incorporating FA5's requirements back into FA1's work (e.g. for the Conceptual Data Model, CDM). The process has been facilitated by bilateral meetings, workshops and a continuous exchange of information. As a foundational element of this process, Deliverable 25.1 from work package 25 in FA5 was provided as a formal specification for developments in FA1, outlining the functional and technical requirements for the seamless freight technical enablers. Work packages within FA5 are interconnected both according to the original plan, with each work packages specialising in a distinct technology/system development, and within the demonstration groups that have been defined later in the process.

The collaborative efforts and dependencies between key systems and the work packages responsible for their developments are shown in Table 1.

The workflow begins with FP5, which is responsible for identifying the needs, operational requirements, and use cases. These requirements then fed into a development phase where key solutions YCS, CDM, ERDS are created. This development phase then produces requirements that is passed to FP1. This table highlights how developments from FP1 and FP5 are interconnected and aligned to enable the Seamless Corridor showcase, as a direct result of contributions from multiple work packages. Each row links a specific system to

its contributing work packages, providing a clear overview of the coordinated structure between the two flagship areas.

Table 1 System to FP's Work package Alignments

System	FA5	FA1
YCS	WP27 - Real-time and short-term Dynamic Dispatching Tools	WP4 - Development - Integration of planning systems and processes including cross-border planning WP5 - Demonstration - Integration of planning systems and processes including cross-border planning
CDM	WP32 - Seamless Data Availability and Data Exchange WP29 - Standardised European Railway Checkpoint at Borders and Other Operational Stop Points.	WP30 - Conceptual Data Model and Semantic Dictionary Evolution
ERDS	WP32 - Seamless Data Availability and Data Exchange	WP31 - Federated Data Space
YCMS	WP26 - Seamless Planning of Rail Freight Services WP27 - Real-time and short-term Dynamic Dispatching Tools	WP4 - Development - Integration of planning systems and processes including cross-border planning WP5 - Demonstration - Integration of planning systems and processes including cross-border planning

Figure 1 shows the coordination of transversal topics between FP1 and FP5. The coordination with FP1 as well as other work packages within the Seamless cluster has been characterised by a collaborative and iterative process.

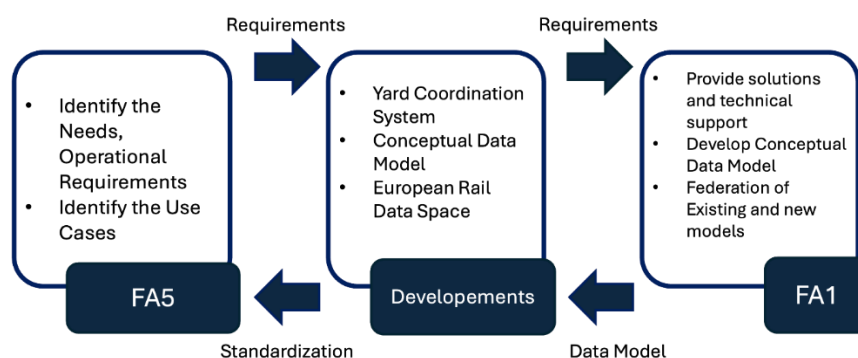


Figure 1 The workflow for coordination of requirements from FA5 for developments in FA1.

FA1's role is to provide solutions and technical support, focusing on developing a Conceptual Data Model and creating a federation of existing and new models, such as

ERDS. The outcomes from FA1's work generate new requirements that are fed back into the development phase, creating a continuous loop of refinement and improvement. In parallel, the development phase also provides input for standardization back to FA5, completing the cycle. This shows that FA5 initiates the process and defines the requirements, while FA1 builds on these to provide technical solutions, with a strong feedback loop ensuring the final products are well-aligned and standardised.

Example: Conceptual Data Model (CDM) Collaboration

The CDM embodies a strong collaboration between FP1 MOTIONAL and FP5 TRANS4M-R. The operational needs and use cases are defined in FA5 (via WP29 and WP32), while FA1 provides the technical realisation of the CDM and its alignment with existing European standards. The workflow is iterative:

- **FA5** specifies the operational and business requirements (e.g., ERC functions and demonstrator needs).
- **FA1** translates these into the CDM structure, federating existing models and ensuring compliance with TAF TSI and related regulations.
- The resulting CDM enables data interoperability across systems deployed in FA5 demonstrations, such as ERC and ERDS.
- Feedback from FA5 demonstrations is fed back into FA1 for refinement and standardisation.

This interaction ensures that the CDM not only addresses local demonstrator needs but also contributes to the long-term goal of a unified data model.

Figure 2 illustrates this example of CDM alignment between the two projects.

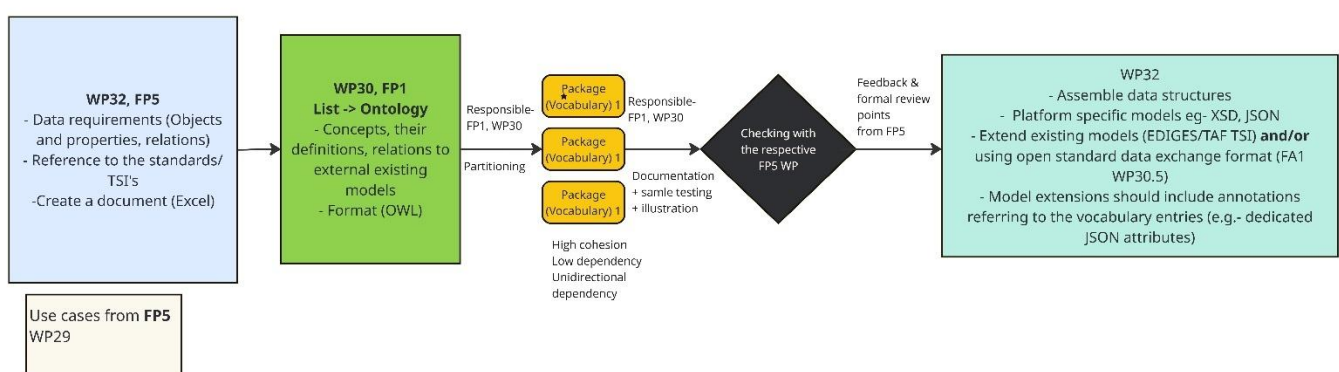


Figure 2 Example of the alignment workflow between FA1 and FA5.

5.3 Measurable demonstration KPIs & Technical Enablers

5.3.1 Evaluating benefits and corridor performance

The assessment of benefits within the Showcase Seamless Corridor (WP33) will be structured around the Key Performance Indicators (KPIs) derived from the MAWP. This

approach is essential to quantify the realized improvements. The KPIs in the MAWP include:

- **KPI 5.4:** Reduce average transportation time on reference corridor
- **KPI 5.5:** Reduce operational dwell time at borders and other handover points
- **KPI 5.6:** Reduce the number of additional operational stops
- **KPI 5.7:** Reduce handling/ response time for ad-hoc cross border path requests
- **KPI 5.8:** Reduce handling/response time for connected comprehensive multimodal offers
- **KPI 5.9:** Reduced energy consumption and reduced footprint through less stops and increased use of multimodal railways transport.

The KPIs relevant in this deliverable, relating to the demonstration group (later introduced in Chapter 6) are KPIs 5.4, 5.5, 5.6, 5.7, and 5.8.

To enable a structured, comparative analysis across different systems and accurately measure the impact of the integration with Destination FA1, a defined set of **generic measurements** has been established. These metrics provide a framework for evaluating key operational efficiencies, specifically focusing on improvements in planned versus actual times for loading at yards/terminals and transit times along the line. Furthermore, the methodology assesses the predictability of Estimated Times of Departure and Arrival (ETD/ETA) and tracks the number of operational stops encountered. These generic measurements are further described in each system section (see Chapter 5.4). The generic measurements are:

- 1 a. Planned time of a loading unit/train in a yard/terminal
- 1 b. Planned time of a train/loading unit on the main line
- 2 a. Deviation of actual times from planned times in a yard/terminal
- 2 b. Deviation of actual times from planned times on the main line
- 3 a. Actual time a loading unit/train spends in a yard/terminal
- 3 b. Actual time a loading unit/train spends on the main line
4. Predictability of trains along their route
5. Number of operational stops, including the main line

The aggregated data resulting from these measurements will be used to determine the demonstration's direct contribution to the broader seamless freight KPIs, as per the MAWP. The overarching narrative is dedicated to demonstrating how this ecosystem approach—which connects systems and facilitates fluid data exchange—translates directly into tangible benefits such as reduced lead times and improved punctuality for international rail freight operations.

To assess how a system contributes to these generic measurements, there are three potential ways of assessing benefit:

Real-life measurement (RLM): Improvement of a measurement is calculated using real-life reference data relevant for any time horizon (long-term, short-term or operational). Considering the TRL level reached in Wave 1, with no full-scale operational implementation and use of any development, this method cannot be used.

Simulation: The system assesses benefit by using simulated values. Especially relevant when real data is hard to get, or when the system/algorithm/component is at a low TRL.

Expert estimation (EE): An expert, e.g. an infrastructure manager or operator, gives his opinion on how the system contributes to the specific measurement.

5.3.2 Linking Technical Enablers to D33.1 Objectives

The coherence and success of the Seamless Corridor Showcase (D33.1) depend on the integration and interoperability provided by several foundational **Technical Enablers** (TEs) developed across different WPs. These enablers, rooted in data sharing concepts (WP32), collectively realize the goal of seamless planning and operational management across the corridor. The Technical Enablers relevant are:

- **TE 9:** Models and Systems for integrated timetable planning with Destination 1 on selected European corridors
- **TE 10:** Dynamic dispatching systems
- **TE 15:** Seamless data availability and data exchange

How the different systems developed within Seamless relate to the goal of demonstrating these TEs will be described further in each system subchapter (5.4.1-5.4.4).

5.4 Developments from FA1 demonstrated in FA5

The developments within FA1 that are planned to be demonstrated within WP33 include the following systems:

- YCS – Yard Coordination System
- CDM – Conceptual Data Model
- ERDS – European Rail Data Space
- Yard-CMS – Yard Capacity Management System

5.4.1 Yard Coordination System (YCS)

Yard Coordination System (YCS) 2.0 is intended to help actors at a marshalling yard coordinate their usage of the arrival and departure tracks of the yard. YCS has been developed for the marshalling yard in Malmö, Sweden, which has a combined arrival and departure yard. The tracks in the arrival and departure yard are used by a freight railway undertaking and a multimodal terminal operator, while the planning of the track usage is made by the infrastructure manager, Trafikverket. The planning is based on the arrival

and departure times of trains and on the demands of the railway undertaking and the terminal operator.

Currently, no central planning support system (like YCS) is used in Malmö, which makes it cumbersome for the actors (the railway undertaking, the terminal operator, and the infrastructure manager) to access updated information about each other's plans. This makes proactive problem-solving hard. There is thus a large potential for better coordination of the track usage for different operations (shunting movements, maintenance, parking, and operations connected to arriving and departing trains).

All planning changes that are made in YCS are logged and available in Deplide, a data sharing platform which has been developed in previous projects by RISE Research Institutes of Sweden and used as a demonstrator tool.

YCS will be part of the demonstration group covering data exchange regarding traffic between Malmö and Alnabru. To be more specific, YCS will be involved in the demonstration of data sharing for the following three types of data:

- Arrival and departure times for trains, from Digital Graf (a traffic management system used by Trafikverket) via Deplide to YCS
- Cross-border operational information regarding arriving international trains, from Deplide to YCS.
- Track assignment information, from YCS to Deplide

5.4.1.1 KPIs and Technical Enablers

This section describes how YCS contributes to the KPIs, followed by the Technical Enablers in the next. The purpose of YCS is to help involved actors coordinate the track usage at a yard. Thus, the main idea of the system is not to affect the KPIs discussed here. However, a secondary effect of improved coordination *may* be decreased handling times at the yard. Also, YCS will make evident if planned operations at the yard conflict with planned arrival or departure times (for example, if operations concerning a departing train will not be finished before the planned departure time). Note, however, that users never change arrival and departure times in YCS. Rather, all such changes are made in the traffic management system, from which they are propagated to YCS.

Possible contributions by YCS to the **KPIs** and the **generic measurements** are assessments and will be informal and indirect: the development of YCS is guided by continuous input from expert users, to ensure that the system will improve coordination at the yard as much as possible, but no actual comparisons of processes with and without the system will be made.

One contribution is that *handling times at the yard become better synchronized with arrival and departure times*, an assessment classified as an expert estimation (EE) and linked to generic measurement 2 a. and KPI 5.5. Additionally, the system is expected to lead to

decreased handling times at the yard, which also impacts KPI 5.5 and relates to generic measurement 3 a.

Beyond yard-specific metrics, the YCS facilitates a *decrease in the total time from origin to destination for wagons and loading units that pass through the yard*, supporting KPI 5.4 under generic measurement 3 a. Furthermore, as a secondary effect identified as YCS-A1, the system *improves the accuracy of the Estimated Time of Arrival (ETA) at the destination for trains whose origin is the YCS-equipped yard*, a contribution that aligns with generic measurement 4 and KPI 5.4.

YCS plays a role in supporting the validations and demonstration of key **Technical Enablers (TE)** within the Seamless project.

For **TE9 (Models and systems for integrated time planning with Destination 1 on selected European corridors)** the YCS system displays delays for arriving international trains, enhances the predictability of ETD for both domestic and international trains from the marshalling yard and contributes to robustness of the entire marshalling yard. See also the KPI relevance above.

For **TE10 (Dynamic dispatching system)**, the YCS receives planned data from the operational system Digital Graf via Deplide. The data from Denmark is based on the standardized TAF TSI format. The processed data from YCS is continuously shared with Line manager, Yard manager and Terminal manager via a graphical user interface and forms the basis for decisions regarding track allocation from a “time window” perspective.

For **TE15 (Seamless data availability and data exchange)**, the YCS as mentioned above uses the TAF TSI standard.

5.4.2 Conceptual Data Model (CDM)

The Conceptual Data Model (CDM), developed in FA1 MOTIONAL (WP30), is a key enabler for standardised and interoperable data exchange across different railway systems and stakeholders. Its design is based on requirements derived from many sources, such as the European Railway Checkpoint (ERC) use cases identified in FA5 WP29 (aligned to FP3, WP27) and WP32 (D29.1 and D32.2). These use cases include cross-border train inspections, train composition verification, brake testing, automated gate operations, weight and dimension checks, and shunting yard arrivals.

The CDM is an ontology-based framework to harmonise information exchange across the European railway domain. Rather than being a single monolithic model, the CDM federates a set of existing standard models—such as TAF TSI, GCU, EVN, and RID—and expresses them through ontologies, ensuring semantic consistency and machine-readable interoperability.

Using the operational requirements defined in FA5 WP29, suitable domain models are identified, adapted, and integrated into the CDM federation. Its structure covers core

entities such as trains, vehicles, checkpoints, timestamps, and Intermodal Loading Units (ILUs). This approach ensures that operationally critical information—like train identifiers, wagon positions, hazardous goods, or checkpoint coordinates—can be exchanged consistently across systems. By doing so, the CDM provides a common semantic layer that enables interoperability between infrastructure managers, railway undertakings, and terminal operators, while also serving as a long-term foundation for Europe's federated data governance in the rail sector.

5.4.2.1 KPIs and Technical Enablers

To determine how the use of CDM impacts the successful railway freight operation, the following KPIs from the MAWP are relevant:

- KPI 5.4: Reduce average transportation time on reference corridor
- KPI 5.5: Reduce operational dwell time at borders and other handover points
- KPI 5.6: Reduce the number of additional operational stops
- KPI 5.7: Reduce handling/response time for ad-hoc cross border path requests
- KPI 5.8: Reduce handling/response time for connected comprehensive multimodal offers
- KPI 5.9: Reduced energy consumption and reduced footprint through fewer stops and increased use of multimodal railways transport.

and these will be evaluate using Real-life measurement (RLM), Simulation and Expert estimation (EE).

In this way, the impact of CDM can be evaluated as follows:

KPI 5.4: Reduce average transportation time on reference corridor

The CDM provides a unified view of the entire corridor, fusing fragmented data from different infrastructure managers/Railway Undertaken/Logistic Operator onto a common language. For instance, instead of each country having a different name or definition for "maximum speed", "Load Unit", "signal location", etc., the CDM harmonizes them. Improving the end-to-end path optimization, facilitating the exchange of data and its exploitation from any point in the corridor, and making possible to exploit them using a unique criterion.

Where – for instance – an algorithm can now be defined to analyse a train's journey from Malmö (Sweden) to Barcelona (Madrid) as a single data set. It can identify that a specific TSR (Temporary Speed Restriction) in one country consistently creates a bottleneck that could be mitigated by adjusting the departure time or speed profile in the preceding country, an impossible pattern to determine if there are silos or non-harmonized definitions and data.

The methods for evaluation are:

- Simulation: Create a digital twin of the reference corridor using the CDM as the data backbone. Simulate train journeys with the current, fragmented data model (selecting appropriate borders) vs. the harmonized CDM. Measure the reduction in total journey time due to optimized, conflict-free paths generated from the unified data.
- RLM: After implementing systems based on the CDM, compare the actual average transportation times on the corridor over the last period against historical baseline data.

KPI 5.5: Reduce operational dwell time at borders and other handover points

Borders are where data variations are highest, different culture, criteria or idiosyncrasy generates slight variations and nuances in the different concepts and definitions. One country's "train ID" might be a different data type than the next countries. A CDM provides a common data language for handover. It defines exactly what information needs to be exchanged, in what format, and what it means (e.g., "Traction Mode" is defined once). This enables the automation of border data exchange.

In this way, as a train approaches a border (in which both countries use a common CDM), the CDM-based system in Country A can automatically map its data to the CDM structure and transmit it to Country B's system before the train arrives. Country B's systems can validate the path, confirm the load, and prepare train consistency, all without manual data entry, minimizing the human intervention.

The methods for evaluation are:

- RLM: Measure the average time a train spends from "arrival at border signal" to "departure from border signal" before and after the deployment of CDM-based data exchange interfaces.
- EE: estimate the reduction in time spent on administrative and communication tasks during the handover process and compares with previous scenario.

KPI 5.6: Reduce the number of additional operational stops

Additional stops often happen because of poor data quality and/or data mismatching or data visibility. A lack of knowledge of a composition's data associated with its precise length, weight, or braking capability may cause its non-acceptance by the Railway Administrator on a given line/route. A CDM ensures that real-time, accurate train composition and performance data is available to all decision-makers.

The railway administrator considering holding a train for a freight path can query the CDM. The model confirms the train adapts to the traffic and load conditions enough to take the path safely. This real-time insight prevents an unnecessary stop, keeping the train moving.

The methods for evaluation are:

- Simulation: Run a traffic management simulation using historical traffic patterns. In Scenario A, traffic managers have limited data. In Scenario B, they have access to the full, unified view provided by the CDM. Count the number of additional stops generated in each scenario.
- RLM: Analyse train journey reports to count the number of unplanned stops. Correlate a reduction in these stops with the rollout of systems that rely on the CDM for accurate train data.

KPI 5.7: Reduce handling/response time for ad-hoc cross border path requests

An ad-hoc request requires multiple IMs to check capacity on their networks simultaneously. Without a CDM, this involves emails, phone calls, and manual data re-entry. With a CDM, a single digital request containing the standardized train data (from the CDM) can be automatically routed to the relevant IMs' capacity management systems, which can also use the CDM to understand the request and return a harmonized offer.

For instance, an operator needs a last-minute path. They input the request into a front-end app built on the CDM. The system automatically checks the availability with three different IMs in seconds, returning a single, combined offer for the entire cross-border journey.

The methods for evaluation are:

- RLM: Measure the average time from the submission of an ad-hoc path request to the delivery of a firm, usable path offer. Compare this metric before and after the implementation of a CDM-based path request and coordination system.
- EE: Ask international path coordinators how many hours per week they save on manual communication and data reconciliation for these ad-hoc requests.

KPI 5.8: Reduce handling/response time for connected comprehensive multimodal offers

Multimodal offers (e.g., Train, Ship and Truck) can be incredibly complex because they involve completely different domains (Rail, Port, Maritime, Road, etc) with their own data standards. A railway can CDM acts as the core translation hub, exchanging multidomain data acting as the referee.

For instance, a logistics provider wants a quote for moving a container from a factory in Warsaw to the port in Gdansk and then on to Barcelona in Spain. A CDM-based system can link the truck's arrival at the rail terminal with the specific train's departure, ensuring the container's data is pre-registered and the path is confirmed, providing a seamless, rapid quote for the entire chain.

The methods for evaluation are:

- Simulation: Model a multimodal request process. Measure the time taken to gather information and generate a combined offer using traditional, disconnected systems. Then, simulate the process using a CDM-based integration platform and measure the new response time.
- EE: Interview freight forwarders and multimodal operators to gauge the perceived reduction in complexity and time required to book combined transport offers using the new data-integrated system.

KPI 5.9: Reduced energy consumption and reduced footprint through fewer stops and increased use of multimodal railways transport.

This KPI is a direct consequence of the others, enabled by the CDM:

- Less Stops (from KPI 5.6): By preventing unnecessary braking and accelerating, the CDM directly reduces energy consumption.
- Optimized Driving (from KPI 5.4): A unified view allows for "green driving" profiles to be calculated and adhered to across borders, minimizing fuel/electricity use.
- Increased Multimodal Use (from KPI 5.8): By making multimodal offers faster and more reliable (via the CDM), rail becomes a more attractive option, shifting freight from more carbon-intensive road-only transport.

The methods for evaluation are:

- Simulation: Use a train performance simulator. Input the driving profiles generated by the CDM-optimized paths (from KPI 5.4) and compare the calculated energy consumption against the profiles used in the pre-CDM era.
- RLM: Monitor the current energy consumption data from locomotives (if metered) and correlate improvements with the reduction in operational stops (KPI 5.6). Also, track the modal shift by measuring the increase in container volume moved via the integrated multimodal offers (enabled by KPI 5.8) and calculate the avoided CO₂ emissions compared to road transport.

The CDM also plays a key role in supporting the validations and demonstration of key **Technical Enablers (TE)** within Seamless project.

For **TE9 (Models and systems for integrated time planning with Destination 1 on selected European corridors)** the CDM ensures that time-planning models can access harmonized and interoperable data about trains and vehicles—most of it captured by ERCs—across borders.

For **TE10 (Dynamic dispatching system)**, the CDM enables real-time, semantically consistent data exchange between operational systems. By using standard data models, ensuring machine-readable interoperability, dynamic decision-making processes and adaptive dispatching based on up-to-date operational data is supported.

Finally, for **TE15 (Seamless data availability and data exchange)**, the CDM directly provides the semantic and structural foundation for seamless data interoperability. Its ontology-based design harmonizes existing standards (TAF TSI, GCU, EVN, RID), ensuring that data from various systems can be shared, understood, and reused without ambiguity.

5.4.2.2 Success criteria for integration

In this multi stakeholder ecosystem (infrastructure managers, railway undertakings, and terminal operators), successful data integration is not merely a technical achievement but a strategic enabler of collaboration, insight, and value. The predefined Conceptual Data Model serves as the single source of truth—the canonical blueprint—that guides this integration. However, the mere existence of this CDM does not guarantee success. This chapter outlines a structured approach to planning definitive success criteria for integration initiatives, ensuring that the shared model translates into seamless, reliable, and valuable data exchange across all involved partners/stakeholders.

Aligning with the CDM's Strategic Intent

The first layer of success criteria must measure adherence to the CDM's core purpose.

- Criterion 1.1: Semantic Consistency: All integrated messages exchanged between partners/stakeholders can be directly traced to and are semantically aligned with the entities, attributes, and relationships defined in the CDM. (Measured by a documented mapping inventory with < 100% coverage target).
- Criterion 1.2: Partner Onboarding Compliance: New partners can successfully complete a defined onboarding process where their source data is mapped to the CDM, with all mandatory fields and entities fulfilled. (Measured by onboarding cycle time and first-time mapping acceptance rate).
- Criterion 1.3: Model Evolution Management: Changes to the CDM (new versions) are propagated to all partners' integration interfaces within an agreed governance timeframe without breaking existing data flows. (Measured by version adoption rate and regression incident count).

Data Quality & Integrity Criteria

Integration is only as good as the data flowing through it. Success criteria must enforce the quality dimensions defined by the CDM.

- Criterion 2.1: Conformity to CDM Standards: Data values adhere to the formats, code lists, enumerations, and data types specified in the CDM (e.g., dates in ISO 8601, codes from approved value sets). (Measured by % of records passing syntactic validation rules).
- Criterion 2.2: Referential Integrity: Relationships between data objects (e.g., a `Customer` must have an associated `Country` code that exists in the reference

table) are maintained across partner systems as defined in the CDM. (Measured by orphaned record counts in key relationships).

Criterion 2.3: Business Rule Validation: Critical business rules implied or defined within the CDM (e.g., "`Order\_Total` must equal sum of `Line\_Item\_Amounts`") are validated at the point of integration. (Measured by % of transactions/records failing business rule validation).

Operational & Performance Criteria

These criteria ensure the integrated system is reliable, timely, and efficient.

- Criterion 3.1: End-to-End Latency: Data created or updated in a source partner/stakeholder system is available in the integrated view or target system within the agreed Service Level Agreement (SLA)—e.g., near-real-time (seconds/minutes) or batch (hourly). (Measured by 95th/99th percentile latency).
- Criterion 3.2: Integration Process Reliability: The integration pipelines (ETL/ELT, APIs, messaging) have a defined uptime and success rate (e.g., 99.5% successful execution of scheduled jobs, < 0.1% unplanned downtime). (Measured by Mean Time Between Failures - MTBF).
- Criterion 3.3: Error Handling & Resolution: All integration errors are logged, classified (e.g., mapping, validation, system), and have defined resolution paths and timeframes (SLOs). (Measured by mean time to resolution - MTTR for critical errors).

Business Outcome & Value Criteria

Ultimately, integration must deliver tangible value. These criteria connect technical execution to business objectives.

- Criterion 4.1: Unified Reporting & Analytics: Key business reports and dashboards defined as requirements (e.g., cross-partner sales performance, consolidated inventory) are successfully generated using the integrated data based on the CDM, without manual reconciliation. (Measured by report accuracy and reduction in manual effort hours).
- Criterion 4.2: Process Efficiency Gains: Specific business processes (e.g., order-to-cash, partner settlement) show measurable improvement in cycle time, cost reduction, or error reduction due to streamlined data exchange. (Measured by KPIs specific to those processes).
- Criterion 4.3: Partner Satisfaction: Key user groups from each partner report increased satisfaction with data accessibility, accuracy, and timeliness for their operational and decision-making needs. (Measured via periodic surveys or Net Promoter Score for data services).

Governance & Compliance Criteria

Sustainable integration requires clear ownership and control.

- Criterion 5.1: Data Lineage & Auditability: Full lineage from source partner data to integrated CDM-aligned data and downstream consumers is documented and traceable for critical data elements. (Measured by % of critical elements with automated lineage coverage).
- Criterion 5.2: Security & Access Control: Access to integrated data is governed by a role-based model aligned with partner agreements, and all data in transit and at rest is secured according to policy. (Measured by audit findings and security incident count).

5.4.3 European Rail Data Spaces (ERDS)

Data spaces facilitate data sharing while addressing the technical, organizational and legal challenges in cross-organisational use cases. To tackle these challenges, International Data Spaces Association (IDSA) defines the necessary governance frameworks, protocols and standards, where such specifications are agnostic to the underlying domains and technologies. Consequently, data spaces enhance the trust among its participants and enable technical, semantic and legal interoperability in sharing data.

IDSA outlines several components that are essential to operate and participate in a data space. The trust among participants is derived from such components, where they are evaluated by evaluation facilities, registered by governance bodies, authenticated and continuously monitored through complementary services. In addition, a participant can publish data offers and engage in contract negotiations by complying to Data Space Protocols (DSPs) that ensure conformity, interoperability and extensibility to support diverse data sharing requirements.

The European Rail Data Space (ERDS) has been delivered by FA1 MOTIONAL to facilitate data sharing use-cases across all Flagship Areas. A collaboration has been established between FA1 and FA5, where efforts are currently underway to onboard partners (CEIT, INDRA, RENFE and ADIF) to ERDS and enable data transfers related to the Can Tunis use-case demonstration in FA5 (see chapter 6.2.2). Figure 3 shows an architecture of this demonstration, where data are collected through on-board sensors and Intelligent Video Gates (IVGs), stored in databases hosted by the relevant partners and subsequently shared across the organizations using data Space Connectors. As a prerequisite, data offers with relevant metadata (e.g. source/sink endpoint, access token) are published by providers and contract agreements are established between organizations via Connectors. In particular, train compositions calculated based on the collected data (i.e. from on-board sensors and IVGs) will be transferred between CEIT and INDRA locally (on the IVG), whereas INDRA shares Train composition through the Federated Data Space (FDS) using the CDM, with RENFE and ADIF (at this stage integrating a specific dashboard)

to accomplish the requirements associated with the end-systems, such as Traffic Management System and the TOS supplied by INDRA.

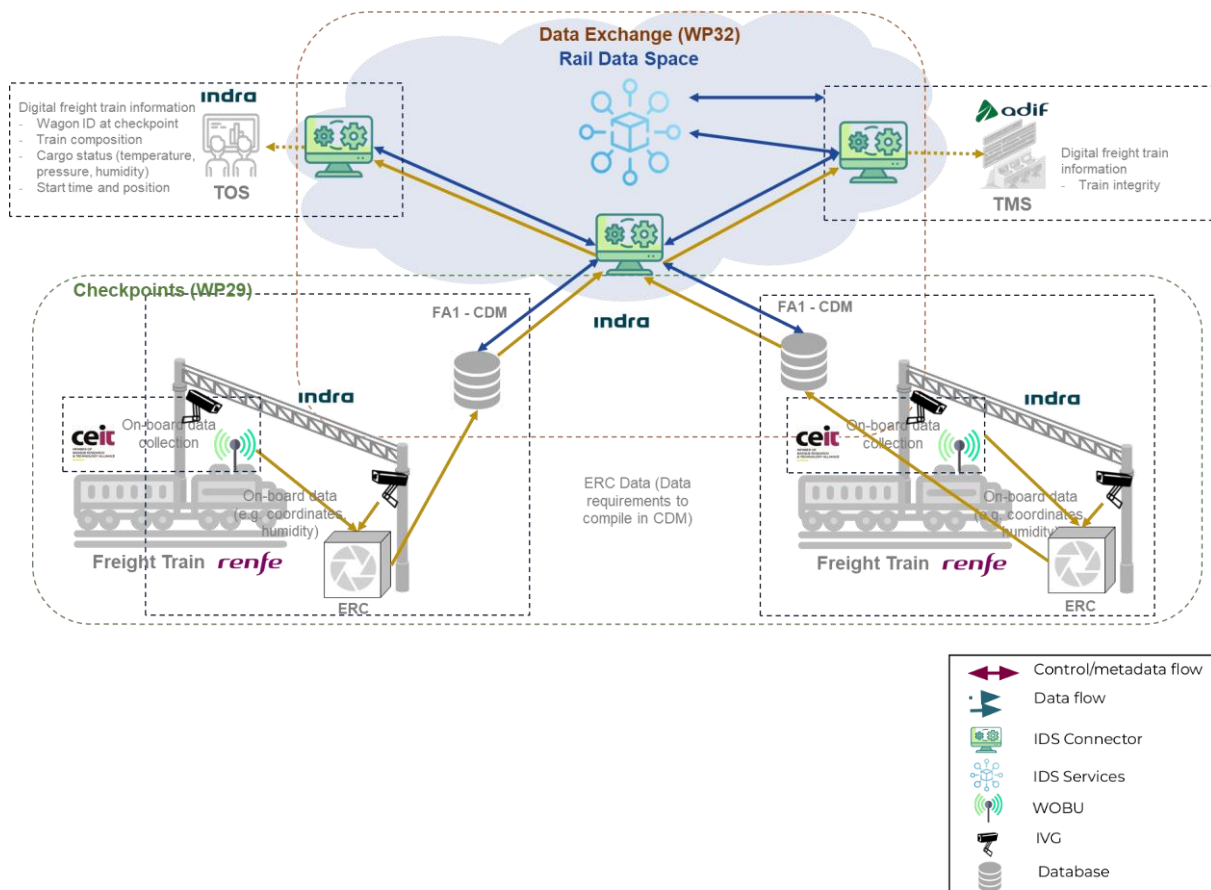


Figure 3 Demonstration Architecture for data collection through on-board sensors and IVGs

Figure 3 shows an architecture of this demonstration, where data is collected through on-board sensors and Intelligent Video Gates (IVGs), stored in databases hosted by the relevant partners and subsequently shared across the organizations using data Space Connectors.

5.4.3.1 KPIs and Technical Enablers

The implementation of the European Rail Data Spaces (ERDS) introduces an interoperable and federated data exchange architecture aimed at optimizing freight rail transport operations at the European level and, in particular, improving the efficiency of processes at European checkpoints. In this context, KPIs 5.4 to 5. constitute a set of indicators aimed at assessing the functional and operational impact of real-time data availability, semantic standardization, and improved cross-border coordination enabled by the ERDS.

KPI 5.4 focuses on reducing average transport time in reference corridors, a parameter that is directly dependent on the efficiency of capacity planning and dynamic management. The integration of data from multiple operators, infrastructure managers,

and terminals enables more accurate optimization models and early identification of disruptions and conflicts. This ability to make operational adjustments based on shared information helps to reduce travel times and stabilize variations within the corridor.

In relation to cross-border procedures, **KPI 5.5** addresses the reduction of operational waiting time at borders and transfer points. The availability of harmonized data relating to train composition, digital documentation, and operational statuses reduces the need for manual checks or redundant processes. The ERDS acts as a reliable information repository that allows infrastructure managers to execute handover procedures more efficiently, reducing accumulated delays at points where greater inefficiencies traditionally occur.

KPI 5.6, relating to the reduction of additional operational stoppages, reflects the extent to which the ERDS facilitates more predictable and coordinated operations. Many of these unplanned events arise from a lack of visibility regarding track availability, terminal occupancy, or the status of rolling stock. Access to up-to-date data mitigates the need for preventive stoppages and contributes to a more rational use of infrastructure.

In parallel, **KPI 5.7** assesses the system's ability to reduce response times to ad hoc requests for cross-border journeys. Distributed access to information on residual capacity, temporary constraints, and operating conditions on different national networks speeds up the process of analysing and accepting requests. The ERDS provides the technological basis for managers to calculate feasibility in a significantly reduced time frame.

KPI 5.8 focuses on multimodal integration, evaluating the reduction in the time required to generate connected offers that combine rail with other modes of transport. By enabling data exchange between heterogeneous systems, the ERDS facilitates the automated composition of complete logistics solutions, increasing responsiveness in scenarios where decisions must be made with incomplete or fragmented information.

To measure these effects objectively, generic measurements form the methodological basis. Measurements of planned and actual times, both at terminals and online, as well as their deviations, make it possible to determine the system's capacity to reduce operational uncertainty. Train predictability becomes a key parameter for assessing the robustness of data exchange, while the number of operational stops allows for direct quantification of the efficiency generated by increased visibility and coordination. This set of measurements provides a common basis for comparing results between corridors and assessing the incremental impact of specific ERDS functionalities.

The system evaluation is structured around three complementary approaches: real-life measurements, simulations, and expert estimates. **Real-Life Measurements (RLM)** provide empirical evidence based on historical and current operational data, allowing longitudinal improvements to be identified. When the system is still at low levels of

technological maturity or when the available data are insufficient for a conclusive analysis, **simulations** allow behaviours to be extrapolated in different operational scenarios and the potential impact of the ERDS to be assessed under controlled conditions. Finally, **Expert Estimation (EE)** incorporates the experience of industry professionals who are able to contextualize benefits, identify external dependencies, and assess qualitative aspects that cannot be measured directly.

Together, this technical framework of indicators, measurements, and assessment tools allows for a systematic analysis of the ERDS's contribution to improving operational performance in European freight rail transport, as well as its ability to enable more efficient, automated, and sustainable cross-border processes.

The European Rail Data Space (ERDS) plays a pivotal role in enabling and validating key **Technical Enablers (TE)** within the Seamless project by fostering a trusted, federated, and interoperable data ecosystem across the European rail sector.

For **TE9 (Models and systems for integrated time planning with Destination 1 on selected European corridors)**, ERDS facilitates cross-border coordination by enabling access to harmonized and secure data about train movements, infrastructure, and operational constraints. This supports time-planning models with real-time, standardized inputs, improving accuracy and interoperability across national systems.

For **TE10 (Dynamic dispatching system)**, ERDS facilitates dynamic decision-making by enabling secure, peer-to-peer data exchange between dispatching systems. Its governance model ensures data sovereignty while allowing real-time access to operational data, supporting adaptive dispatching and conflict resolution based on live operational conditions.

For **TE15 (Seamless data availability and data exchange)**, ERDS provides the foundational infrastructure for trusted and standardized data sharing. Built on IDSA principles, it ensures semantic interoperability and full traceability of data transactions, enabling seamless integration of diverse systems and actors in the rail ecosystem.

5.4.3.2 Success criteria for integration

The integration of the European Rail Data Spaces (ERDS) is considered successful when it demonstrates clear improvements in data interoperability, operational performance and cross-border coordination within the European freight rail system. The following success criteria provide a concise evaluation framework:

Interoperability and Standards Compliance: Systems participating in the ERDS must exchange data reliably using the common semantic models, APIs and governance rules defined by the ERDS architecture. Full interoperability – technical and semantic – is essential to ensure consistent interpretation and reuse of shared data.

Data Quality and Availability: Critical operational data (train position, composition, handover status, path requests, terminal status) must be accessible with sufficient accuracy, completeness and timeliness to support decision-making. Continuous availability of data flows is a key indicator of integration maturity.

Impact on Operational KPIs (5.4–5.): Successful integration must enable measurable improvements in the KPIs related to transport time, border dwell time, additional operational stops, and response times. Improvements may be demonstrated through real-life data, validated simulations or expert assessments.

Adoption in Real Operational Processes: ERDS functionalities should be embedded in daily workflows across operators, infrastructure managers and terminals. The system must reduce reliance on manual processes and bilateral communication, contributing to more efficient cross-border operations.

Security, Sovereignty and Regulatory Compliance: Data exchanges must comply with ERDS trust and governance frameworks, ensuring secure access control, traceability and alignment with relevant European regulations (e.g. NIS2, GDPR where applicable, TAF/TAP TSI).

Scalability and Replicability: The integration approach must be applicable across multiple corridors, actors and operational environments without significant redesign. Scalability demonstrates that ERDS operates as a federated, Europe-wide ecosystem rather than a corridor-specific solution.

Sustained Use and Stakeholder Acceptance: Continued use of ERDS data and services by operational stakeholders – beyond pilot phases – is a key indicator of success. Stable or increasing adoption reflects perceived value, usability and integration into established operational practices.

Operational and Economic Benefits: The system should demonstrate reductions in delays, operational costs, administrative overhead and environmental impact. These benefits validate ERDS as a strategic enabler for improving the competitiveness and sustainability of European rail freight.

5.4.4 Yard Capacity Management System (Yard-CMS)

The Seamless Planning functions of the Yard-Capacity Management System focus not only on the yard (and its capacity) itself, but also on the connection with national train path planning in the PCS (Path Coordination System) tool. With the developments done in the scope of WP26 and FP1 MOTIONAL WP4/WP5, a train path planned in the various planning systems like TPS (Train Planning System) and confirmed in the PCS tool thus accounts for both, mainline (MOTIONAL) and yard (TRANS4M-R) capacity constraints. This eliminates the need for manual, iterative coordination between the national systems, replacing it with automated, standards-based data exchange.

The exchange of information supports the Telematics TSI TAF (TAF TSI) standard, e.g. Path Details and Temporary Capacity Restriction messages, which enable real-time, interoperable communication between disparate systems. New functionalities also support short-term re-planning scenarios, allowing dynamic adjustments to train paths in response to yard capacity issues, infrastructure restrictions, or operational disruptions. These advances collectively support a scalable and future-ready planning environment that improves the reliability, responsiveness, and efficiency of European rail freight.

Through the developments carried out in FP5 TRANS4M-R (WP26) and FP1 MOTIONAL (WP4/WP5), the Yard-CMS ensures that train paths confirmed in PCS already reflect both mainline and yard capacity constraints. This eliminates redundant negotiations, reduces mismatches between yard availability and allocated train paths, and allows for more reliable and efficient planning across borders. The solution is fully interoperable with the Telematics Applications for Freight (TAF TSI) standard, enabling the exchange of real-time capacity information through messages such as Path Details and Temporary Capacity Restrictions.

In addition to long-term planning, the Yard-CMS also supports short-term and dynamic re-planning. This functionality is particularly valuable when dealing with operational disruptions, infrastructure restrictions, or sudden changes in yard usage. Automated conflict detection and resolution features help infrastructure managers and operators quickly adapt, ensuring smoother coordination between line and yard processes.

The demonstrations planned within WP33 highlight this integration in two main scenarios:

- **Cross-border path planning:** Two neighbouring infrastructure managers coordinate mainline capacity via CMS-to-CMS interfacing, while PCS provides the standardised platform for exchanging international path requests and offers.
- **Integrated yard-line planning:** Yard-CMS and mainline CMS are connected through an open API using JSON-based message exchange, facilitated by a RabbitMQ broker. This setup showcases seamless interaction between yard and line operations, reducing the need for verbal alignment and manual adjustments.

The Yard-CMS creates a unified planning ecosystem that seamlessly integrates yard and mainline operations through automated, standards-based data exchange and dynamic re-planning capabilities, enabling more reliable and efficient cross-border rail freight coordination across European corridors.

5.4.4.1 KPIs & Technical Enablers

The Yard-CMS contributes to **TE9 (Models and systems for integrated time planning with Destination 1 on selected European corridors)** by enabling truly integrated time planning that seamlessly combines yard and mainline capacity constraints within a unified planning framework. Through its connection with the PCS (Path Coordination System) and integration of TPS (Train Planning System), train paths are now planned and confirmed

while accounting for both MOTIONAL (mainline) and TRANS4M-R (yard) capacity constraints simultaneously. This eliminates the traditional fragmented approach where yard and mainline planning occurred separately, requiring manual coordination. The cross-border path planning demonstration in WP33 showcases how neighbouring infrastructure managers can coordinate mainline capacity via CMS-to-CMS interfacing while using PCS as a standardized platform for exchanging international path requests. This advancement creates a more reliable and efficient planning environment across European corridors, reducing mismatches between yard availability and allocated train paths, and supporting the scalability needed for future rail freight operations.

The Yard-CMS significantly enhances **TE10 (Dynamic dispatching system)** by introducing robust short-term and dynamic re-planning capabilities that respond to real-world operational challenges. The system supports dynamic adjustments to train paths in response to yard capacity issues, infrastructure restrictions, or operational disruptions, moving beyond static planning to adaptive operations. Automated conflict detection and resolution features enable infrastructure managers and operators to quickly adapt to sudden changes in yard usage or unexpected disruptions, ensuring smoother coordination between line and yard processes. The WP33 demonstrations explicitly showcase these dynamic capabilities in both cross-border and integrated yard-line planning scenarios, highlighting how the system can handle real-time operational variability. This functionality is particularly valuable for maintaining service reliability and operational efficiency when dealing with the unpredictable nature of rail freight operations, supporting the responsiveness required for modern dispatching systems.

The Yard-CMS makes a fundamental contribution to **TE15 (Seamless data availability and data exchange)** by replacing manual, iterative coordination with automated, standards-based data exchange that ensures seamless information flow across disparate systems. Full interoperability with the Telematics Applications for Freight (TAF TSI) standard enables real-time exchange of capacity information through standardized messages such as Path Details and Temporary Capacity Restrictions, ensuring that different national and organizational systems can communicate effectively. The technical implementation using an open API with JSON-based message exchange, facilitated by a RabbitMQ broker, demonstrates a modern, scalable architecture for data availability. The PCS serves as a standardized platform for exchanging international path requests and offers, while the Yard-CMS to mainline CMS connection showcases seamless interaction that eliminates the need for verbal alignment and manual adjustments. This creates an interoperable communication environment where real-time capacity information flows automatically between systems, supporting the data-driven decision-making essential for efficient European rail freight operations.

With Yard-CMS and the connected FP1 developments for improved Cross-Border Timetable planning and coordination, which enable a high transparency, automated conflict detection, etc. it is possible to eliminate inconsistencies and identify improvement

potentials in the timetables of single and connected network sections (incl. Cross-border). This is a pre-requisite to reduce operational dwell time at borders and other handover points **(KPI 5.5)** as well as the number of (additional) operational stops **(KPI 5.6)**, in the planned timetable; but also later on in operation when non-optimised coordinated timetables will be more easily affected by distortions. Consequently, all these lead also to a reduced average transportation time on the reference corridor **(KPI 5.4)**. Facilitated by the Yard CMS / TPS any kind of (ad-hoc) cross border path requests will be fully supported and the handling and response time is significantly reduced **(KPI 5.7)**, which has also an effect on the reliability and flexibility of (multimodal) rail based supply chains, which can benefit from ad-hoc paths for additional services, either due to temporary additional volumes or disturbances at other network areas or even on road **(KPI 5.8)**.

6 Showcase of developments within Seamless Corridor

This chapter describes how the development efforts, in alignment between FP1 and FP5, are planned to be showcased within the demonstrations of FP5 WP33.

One demonstration group in terms of integration with FP1 is the demonstration of data exchange use cases, taking place between Malmö in Sweden and Alnabru in Norway. The demonstration group aims to showcase the synergies gained by the interaction between different systems, such as YCS and Yard-CMS, where data exchange enables better decision making.

The second demonstration group will showcase the European Railway Checkpoints (ERC), where the Conceptual Data Model (CDM) and European Rail Data Space (ERDS) are the key developments that will be shown within the demonstration group.

6.1 Integrating Data Exchange Developments in the Malmö-Alnabru demonstration

This chapter describes the planning of the demonstration emphasising on data exchange use cases between Malmö, Sweden and Alnabru, Norway, also referred to as the Malmö-Alnabru demonstration. This demo is an important example of the collaboration between FA5 and FA1.

The primary goal is to showcase synergies of data exchange, ultimately leading to better decision making and operational efficiency, for example when deviations from the planned timetable occurs, enabling later parts of the transport chain to proactively address any necessary changes in the planned operations for affected trains and wagons.

6.1.1 Demonstration of YCS

The collaboration and data exchange enables demonstration of how data from different systems can be integrated with FP1's YCS solutions for yard management. Another aspect is showing how data from the YCS is made available in Deplide, something which might lead to links between local yard planning and broader network management in the future.

6.1.2 Demonstration of Yard-CMS

Using the same data for yards, stations handover stations, and other last mile network areas as for the mainline planning will facilitate a seamless planning and re-planning of the complete train runs. By enabling planning systems like TPS, which cover the various infrastructure areas of the network, to exchange data in standardised TAF/TAP TSI compliant formats, direct and partially also automatic conflict detection and resolution can be facilitated. By this it will be enabled to reach conflict free train paths in shorter preparation times. Besides reducing the regular planning time, this enables also ad-hoc re-planning which might be necessary during daily replanning and operation. Consequently, sharing data between these systems in a standardised way will also lead to a higher timetable quality and will support a higher punctuality. To deploy the demonstrated additional data exchange between the systems on a wider level with a higher TRL, these will be implemented after successful test and demonstrations in the commercial products which are used in several European countries later-on.

6.2 Integrating developments in the Checkpoint demonstration

This chapter describes the planning of the demonstration emphasising the use of European Railway Checkpoints, also referred to as the Checkpoints demonstration. This demonstration shows the development of the Conceptual Data Model framework, developed within FP1, based on the requirements from e.g. WP29 and WP32 in FP5, as well as the developments of European Rail Data Space from WP31 in FP1.

6.2.1 Demonstration of CDM

Within the Seamless Corridor demonstrations, the CDM is meant to be applied in the checkpoint use case. CDM plays a central role in the demonstration of Checkpoints by providing a shared foundation for structuring data. This model ensures that data generated by the checkpoints can be easily exchanged, interpreted, and acted upon across different platforms and stakeholders.

The model provides the semantic backbone for structuring and exchanging data generated or consumed by the ERC systems, such as cross-border inspections, train composition verification, brake tests, wagon condition checks, and hazardous goods control. By representing information in a standardised ontology-based format, the CDM ensures that ERC data can be consumed consistently by different systems. This enables checkpoint results to be shared seamlessly across infrastructure managers, railway undertakings, and terminal operators, thereby improving transparency, compliance with European regulations, and the efficiency of cross-border operations.

The planned demonstration of Checkpoints in Germany and Spain showcases how systems can be aligned towards a common European framework. The benefit of this data exchange shows increased wagon identification accuracy, reduced processing time, and

more efficient yard operations, by showcasing AI-enhanced railway checkpoints. Moreover, the plan is to demonstrate how the wagon number for UIC-compliant wagons is captured in a consistent data structure as they move across multiple checkpoints. This process is part of a broader effort to standardise by defining shared interfaces, modular architectures, and interoperable data formats, rather than enforcing uniform solutions, thanks to the application of CDM. The overarching goal is to transition from fragmented and manual processes to interoperable and intelligent systems that can function across Europe's diverse rail infrastructure.

6.2.2 Demonstration of ERDS

The demonstration uses data from on-board sensors and Intelligent Video Gates (IVGs) to calculate train compositions (see Figure 3). This information is then stored in databases managed by the respective partners. The European Rail Data Space framework enables the exchange of this data. Data Space Connectors are used to transfer data between organizations. For instance, CEIT and INDRA can exchange train composition data, and INDRA shares additional data with RENFE and ADIF for end-system requirements. This process requires data providers to publish "data offers" with metadata, and a contract must be established between organisations.

ERDS will be applied for enabling the data transfers between the partners involved in the Can-Tunis use case. Each organization will implement their own applications to interact with the ERDS components which are developed and maintained by T-Systems (as shown in Figure 4). This enables the organization to share data conveniently with other partners while complying with data space protocols and standards.

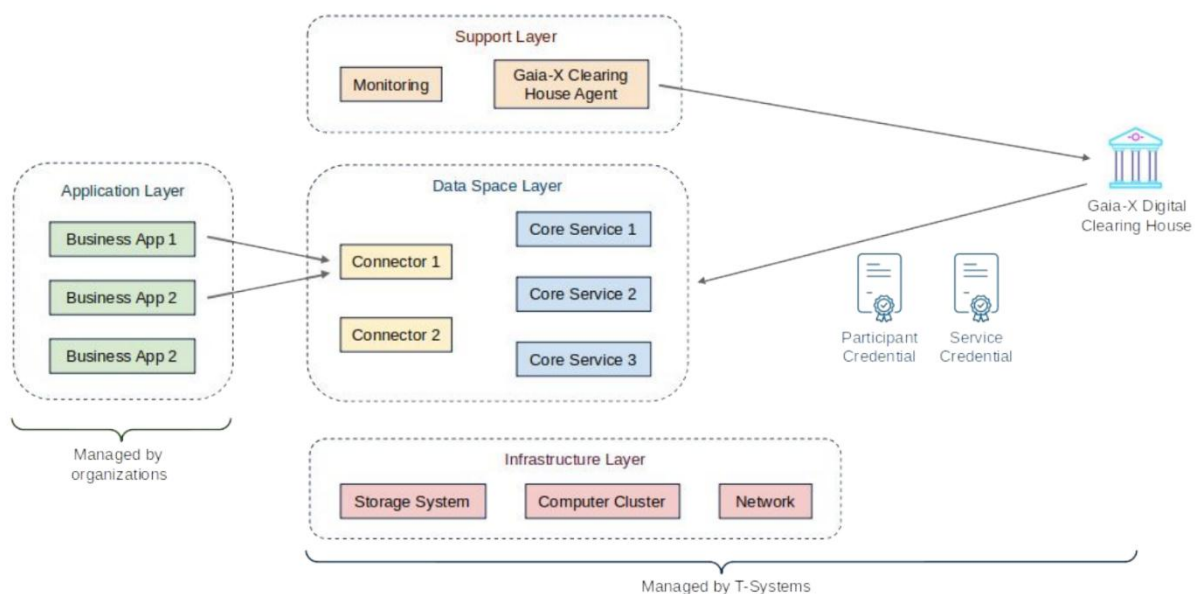


Figure 4 Composition of ERDS with different layers

For example, data will be collected from Wagon Onboard Units (WOBU) sensors and continuously stored in a database managed by CEIT, which will be used to calculate the order of wagons by CEIT's internal services. These train compositions will then be shared with INDRA through the developed applications and ERDS components. As a prerequisite for sharing data, a valid data offer should be published by CEIT in advance, which will be used by INDRA to initiate and complete a contract agreement with CEIT through ERDS. This same process will be adopted to share data between INDRA, RENFE and ADIF, with their corresponding data sources and data sinks.

6.3 Demonstration execution risks

There are some operational, technical and cross-project risks to be addressed in the planning of the demonstrations.

Operational and cross-project risks include the coordination and completion of the tasks within WP33 and previous work packages, but also the challenge of coordinating the efforts in FA1 and FA5. Due to the cross-project nature of the developments, the demonstrations rely on the work progressing as per their respective Grant Agreements and the Multi Annual Work Programme, in parallel. Potential risks are mitigated via continuous alignment between relevant work packages and partners within FA1 and FA5, throughout the projects' lifespan, ensuring that the developments are progressing as planned.

An additional project risk involves the checkpoint in Spain, where administrative setbacks in securing required permits have postponed the installation at Can Tunis. This delay directly conflicts with the original schedule outlined in the Grant Agreement. In response, the partners involved in WP29 (responsible for the planning, setup, and showcasing of checkpoint capabilities) have updated the demonstration timeline, increased progress monitoring, and established more rapid protocols to manage emerging issues.

7 Conclusions

This report details the work and outcomes of Task 33.1, a component of Work Package 33 and the broader FP5-TRANS4M-R project. The primary objective of this task was to plan the Seamless Corridor showcase by identifying suitable operational destinations, engaging key stakeholders, and defining the necessary processes for integration with developments from Flagship Area 1 (FA1).

The task addressed by this deliverable was the need for a comprehensive and coordinated approach to demonstrating the real-world application of technical advancements in a complex, multi-stakeholder environment. To achieve this, a collaborative methodology was adopted, involving frequent bilateral meetings, workshops and coordinated efforts with partners from both FP1 MOTIONAL and FP5 TRANS4M-R.

The main findings of this work are the successful establishment of a comprehensive planning framework and the identification of demonstration groups. These groups are strategically designed to showcase the synergies gained from the interaction of various systems, especially highlighting the data exchange as well as the European Railway Checkpoints (ERC), Conceptual Data Model (CDM), European Rail Data Spaces (ERDS) and Yard Capacity Management System (Yard-CMS), which have been successfully assigned to these demonstration groups, ensuring their planned applications.

Overall, the planned objectives of the task have been achieved. The collaborative efforts have resulted in a structured and a robust plan for the demonstrations, which will serve as next steps in WP33.

A limitation is that the work is currently in the planning phase. Outcomes are based on planned coordination and stakeholder commitments, but the actual implementation and execution of the demonstrations may reveal unforeseen technical or operational challenges.

Dissemination and communication activities will be carried out in coordination with WP1 in FP5 to ensure the project's progress and findings are effectively shared with a wider audience.

The future work will focus on the execution of the demonstration plans of TRANS4M-R, carefully monitoring and documenting the outcomes, followed by analysis of the results, which will be described in Deliverable D33.2 "Results on the Seamless Corridor" reporting on the demonstration activities, and in Deliverable D32.1 "Results from Demonstration" reporting on the data sharing concepts for specific use cases. Any identified gaps will be studied along with the work in the second wave of FA5. The second wave of FA5 will focus on achieving higher TRL levels for the demonstrations.

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