# Deliverable D 5.1
# Demonstrator report

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# 1. Executive Summary

The present document constitutes the Deliverable D5.1 “Demonstrator report” in the framework of the Flagship Project FP1-MOTIONAL as described in the EU-RAIL MAWP. The work is done in WP5 “Demonstration – Integration of planning systems and processes including cross-border planning”. In this deliverable, the validation and evaluation of the 7 demonstrations included in WP5 are presented. The aim is to ensure the target TRLs that allow the verification of the achievement of the goals of WP4 and WP5. Regular dialogue with System Pillar and RailNetEurope has been a part of the work and also a special focus on Malmö–Oslo/Alnabru corridor with demonstrations performed in FP1 WP5, WP12 and FP5.

All demonstrations in WP5 aim at improving the planning and communication processes when new information is given as, for example, ad hoc train paths, updated arrival/departure times, TCRs or other changes that need to be transferred between PCS, CMS and TMS, both locally, nationally and internationally. The 7 demonstrations included in this deliverable and main contribution from them are:

- **Demo 5.1: Cross-border scheduling.** An interface solution is developed that connects the CMS with a centralised PCS. Five test cases were executed successfully, validating the full interaction workflow between the PCS simulator and the CMS.
- **Demo 5.2: International co-ordination of residual capacity in an early ad hoc stage.** A tool for identifying residual capacity for ad hoc train paths is developed. The tool can also be used to generate alternative train paths and evaluate them using simulation to support the planners’ decision making.
- **Demo 5.3: Interfaces for interaction with external national or central planning applications.** A demonstration of how the CMS (TPS.plan) supports bi-directional system-to-system integration with the RNE PCS for the exchange of international path requests and related capacity data, via both the PCS Integration Platform (web services) and the Telematics TSI Common Interface.
- **Demo 5.4: Collaborative yard capacity planning.** Demonstration of how the developed operational planning system (YCS) for the tracks in an arrival/departure yard can be used to improve the planning of yard resources. It is also demonstrated how the information exchange within the tool between line manager, yard manager and terminal manager leads to more efficient operations, reduced manual workload and stress.
- **Demo 5.5: Improved capacity allocation and new processes.** Demonstration of how the CMS generates a file compatible for uploading of Capacity Model data to the ECMT tool currently developed by RNE to improve the alignment of European capacity planning results.
- **Demo 5.6: Integration of traffic management system with network capacity planning.** Demonstration of a seamless integration of TMS with CMS, ensuring that operational plans are consistent and up-to-date across both systems. The implementation of this use case significantly enhances the overall efficiency and resilience of the railway network.
- **Demo 5.7: Integration of network capacity planning with yard and station capacity planning.** Demonstration of the integration of national CMS with station/yard-based (local) CMS to ensure overall and real-time alignment of local and national planning. Through a series of realistic scenarios, the systems' capabilities in conflict detection, resolution, and the efficient management of dynamic yard operations, including new shunting activities were demonstrated.

## 2. Abbreviations and acronyms

| *Abbreviation / Acronym* | *Description* |
|---|---|
| CI | Common Interface (PCS/RNE) |
| CMS | Capacity Management System |
| CPT | Capacity Planning Tool |
| DLT | Distributed Ledger Technology |
| ECMT | European Capacity Management Tool, now replaced with CPT |
| ETA | Estimated Time Arrival |
| ETD | Estimated Time Departure |
| FP | Flagship Project |
| GA | Grant Agreement |
| GDPR | General Data Protection Regulation |
| GTT | Graphical Train Timetable |
| GUI | Graphical User Interface |
| IM | Infrastructure Manager |
| IT | Information Technology |
| JSON | JavaScript Object Notation |
| KAJT | Kapacitet i järnvägstrafiken (Capacity in railway network) |
| LM | Line Manager |
| LTP | Long Term (Capacity) Planning |
| MAWP | Multi-Annual Work Programme |
| PCS | Path Coordination System (hosted by RNE) |
| RNE | RailNetEurope |
| RU | Railway Undertaking |
| STP | Short Term (Capacity) Planning |
| TAF/TAP TSI | Technical Specification for Interoperability, Application Freight/Passenger (Renamed in 2024 to *Telematics TSI*) |
| TC | Test Case |
| TCR | Temporary Capacity Restriction |
| TE | Technical Enabler |
| TeM | Terminal Manager |
| TM | Traffic Manager |
| TMS | Traffic Management System |
| TPS | Train Planning System |
| TRL | Technical Readiness Level |
| TRV | Trafikverket |
| TTR | Timetable Redesign (RNE) |
| TSI | Technical Specification for Interoperability |
| UC | Use Case |
| WP | Work Package |
| YCS | Yard Coordination System |
| YM | Yard Manager |
| XML | Extensible Markup Language |

# 3. Background

The present document constitutes the Deliverable D5.1 "Demonstrator report" in the framework of the Flagship Project FP1-MOTIONAL as described in the EU-RAIL MAWP. The work is done in WP5 "Demonstration – Integration of planning systems and processes including cross-border planning". There are in total 7 demonstrations that will be presented in this deliverable, see Table 3.1.

In order to help organising the work, WP5 is divided into three tasks with a total of five subtasks, listed below:

- Task 5.1 Demo case specification: Setting up concrete demo cases based on the output of WP4 and in relation with WP 8/9, and WP 6/7, WP11/WP12, WP1 3/14 and Destination 5.
  - The task specifies how TRL are reached for:
    - Enabler 1: European cross-border scheduling with international train path planning
    - Enabler 2: Improved capacity allocation using rolling planning and TTR
    - Enabler 6: Integration of planning systems and TMS with a) yard capacity planning and b) station capacity planning
- Task 5.2 development and demonstration of demonstrators to the target TRL: Delivery of min. TRL 5 demonstrator(s) to FP5 WP33 until M37.
  - Subtask 5.2.1 Development of demonstrators for Interfaces for interaction with external national or central planning applications. Demonstration of cross-border planning including Short Term Timetable Planning and process improvement among actors.
  - Subtask 5.2.2 Development of demonstrators for improved capacity allocation and new processes. Demonstrate the integration of new planning processes and the production of standard reports.
  - Subtask 5.2.3 Development of demonstrators for Integration of traffic management system with network capacity planning. The feedback loop between planning and operation will be jointly demonstrated with WP11/12 and WP 13/14.
  - Subtask 5.2.4 Development of demonstrators for Integration of network capacity with yard and station capacity planning. This demonstrator shows integration of nodes and lines using specified interfaces.
- Task 5.3 Demonstration validation: The developed demonstrators are validated by review and feedback loops from results. The validation process comprises workshops, reviews and demonstrations covering the scope of the selected demo cases.
  - Subtask 5.3.1 Conclusion and preparatory work for the next waves. The output of this phase includes suggestions and plans for further continuation of work in the coming waves

This deliverable is based on the input from results in Tasks 5.2 and 5.3, with sections assigned to each demonstrator developed in task 5.2 and includes the evaluation and conclusion of task 5.3. The work in Tasks 5.2 and 5.3 is built on the work in previous work packages in MOTIONAL: WP3 "Specifications of demonstrators for improved strategic and tactical planning of the rail network WP3–WP9" and WP4 "Development – Integration of planning systems and processes including cross-border planning", where most specification and development was done. For a detailed view on the previous work, please see Deliverable 3.1 "Mapping against scope, specification of technical enablers, high-level use cases, high-level requirements, high-level design for demonstrators in WPs 4-9", (FP1-MOTIONAL, 2023) and Deliverable 4.1 "Integration of planning systems", (FP1-MOTIONAL, 2024c).

**Table 3.1 – Demonstrations that are presented in this deliverable**

| Demon-stration | Short description | Leading partner | Technical enabler | Related use case |
|---|---|---|---|---|
| Demo 5.1 | Cross-border scheduling | MERMEC | TE1 | UC-FP1-WP3-17 |
| Demo 5.2 | International co-ordination of residual capacity in an early ad hoc stage | Trafikverket A.E. KTH | TE1 | UC-FP1-WP3-7, UC-FP1-WP3-8, UC-FP1-WP3-9 |
| Demo 5.3 | Interfaces for interaction with external national or central planning applications | HACON | TE1 | UC-FP1-WP3-1, UC-FP1-WP3-2, UC-FP1-WP3-3 |
| Demo 5.4 | Collaborative yard capacity planning | Trafikverket A.E. RISE | TE6 | UC-FP1-WP3-10, UC-FP1-WP3-11, UC-FP1-WP3-12, UC-FP1-WP3-13 |
| Demo 5.5 | Improved capacity allocation and new processes | HACON | TE1, TE2 | UC-FP1-WP3-4 |
| Demo 5.6 | Integration of traffic management system with network capacity planning | HACON | TE2, TE6 | UC-FP1-WP3-5 |
| Demo 5.7 | Integration of network capacity planning with yard and station capacity planning | HACON | TE6 | UC-FP1-WP3-6 |

# 4. Objective/Aim

This deliverable aims to present that WP5 has met its objectives stated in the Grant Agreement. The overall objective in WP5 is to demonstrate and further develop the demonstrator modules in WP5, to ensure to reach the target TRLs that allow the verification of the achievement of the goals of WP4 and WP5. The demonstration environment will be provided by interacting systems or system simulators. A demonstrator cross-border node Malmö for network–yard/terminal is planned.

Several use cases aiming for demonstration in WP5 were identified and detailed in WP3 and WP4. Table 3.2 presents all use cases in WP5, that need to be verified in the demonstrations. For more information on the use cases, see Deliverable 4.1 (FP1-MOTIONAL, 2024c). This demonstration report aims to show that all use cases are verified, all tasks of WP5 are completed and therefore contributing to achieving the overall WP5 objective.

**Table 3.2 – Identified use cases to be verified**

| Use case Id | Use case name | Responsible partners |
|---|---|---|
| UC-FP1-WP3-1 | International late path request placed between X-8 and X-2 | HACON |
| UC-FP1-WP3-2 | International path request placed after X-2 and before X+12 | HACON |
| UC-FP1-WP3-3 | Showing and handling of impact of imported TCR | HACON |
| UC-FP1-WP3-4 | Planning and allocation of capacity for different planning horizons | HACON |
| UC-FP1-WP3-5 | Data exchange between traffic management system (TMS) and local or national capacity management/planning system (CMS) | HACON |
| UC-FP1-WP3-6 | Data exchange between national capacity management/planning system (national CMS) and local, yard-based capacity management/planning system (local CMS) | HACON |
| UC-FP1-WP3-7 | Cross-border ad hoc planning 1 | TRV/KTH |
| UC-FP1-WP3-8 | Cross-border ad hoc planning 2 | TRV/KTH |
| UC-FP1-WP3-9 | Cross-border ad hoc planning and simulation | TRV/KTH |
| UC-FP1-WP3-10 | YCS: Update the initial A/D-yard plan | TRV/RISE |
| UC-FP1-WP3-11 | YCS: Updated planned arrival times | TRV/RISE |
| UC-FP1-WP3-12 | YCS: Wagons for outbound train not ready for departure on time | TRV/RISE |
| UC-FP1-WP3-13 | YCS: New shunting need from YM | TRV/RISE |
| UC-FP1-WP3-14 | YCS: Cleanup of short-term track allocation plan | TRV/RISE |
| UC-FP1-WP3-15 | YCS: Adjust track allocation plan according to changes from CMS | TRV/RISE |
| UC-FP1-WP3-16 | YCS: Adjusted handling capacity of yard operations | TRV/RISE |
| UC-FP1-WP3-17 | CMS decision supporter to plan a cross-border path | MERMEC |

# 5. Report structure

The report structure for all demonstration reports in FP1 MOTIONAL is set in Deliverable 2.4 “Demonstration strategy”, see FP1-MOTIONAL (2024a). This deliverable follows the structure from Deliverable 2.4 with only minor adjustments: This report structure chapter is added for increased readability and a general method and validation chapter is added so method and validation strategies performed by everyone can be written only once instead of repeated in every chapter, which increases readability and reduces the total text amount.

After the general method and validation chapter, each demonstration has its own chapter with subchapters describing demonstration specific method, developments, planning, validation and results. This helps the reader to focus on one demonstration at a time and easier browse through content in order to find the information the reader is interested in. This is followed by a chapter describing interactions with other Flagship Projects (mainly FP5) and lastly conclusion and references.

# 6. General method and validation

Method and validation strategies valid for all demonstrating partners in WP5 are presented in this chapter.

## 6.1. Workflow

During WP5, all partners have followed the general working method for FP1 – MOTIONAL, described in Deliverable D2.4, (FP1-MOTIONAL, 2024a) with four phases:

1. Preparation phase
2. Implementation phase
3. Execution phase
4. Evaluation phase

In the preparation phase, all planning and setup for the validation and dissemination events is performed, such as identifying end-users, stakeholders, making a time and communication plan and defining test data.

In the implementation phase, the focus is to ensure that all demonstrations are ready for the validation events. Here training material for end-users is created, data is collected and validated for the specific validation events and the demonstrations are thoroughly tested in various way. All common steps in the implementation phase can be seen in Deliverable D2.4. It is also during the implementation phase that the last integration and functions are built in.

The execution phase consists primarily of the validation event. For some demonstrations, this phase also includes repeatedly internal demonstration runs in order to gather statistics and investigate the demonstrator behaviour in order to be able to evaluate the results.

In the evaluation phase, the results from the validation event are gathered, processed, analysed and presented. The results can be both quantitative, such as computation or data transfer time, and qualitative, such as usability feedback from end-users. The results are then presented to stakeholders and the JU at a dissemination event and in this deliverable. Demos 5.1, 5.2, 5.3, 5.4 and 5.5 were presented at the dissemination event “Cross-border planning” in Solna, Sweden, on the 13th of May 2026 and Demos 5.6 and 5.7 were presented at the dissemination event “Intelligent Planning: Boosting planners’ power with smart algorithms and simulations” in Paris, France, on the 12th of May 2026.

The specific work done in each of the four phases is described in each demonstration chapter respectively.

## 6.2. Validation strategy

The demonstration technical validation, corresponding to TRL4, is performed already in WP4 and presented in Deliverable 4.1 “Integration of planning systems”, (FP1-MOTIONAL, 2024c). Some more technical development is performed in WP5 but expected to be verified in a similar way, by

each demonstrating partner. Focus in WP5 is instead the overall validation, connected to the target TRLs (TR5 for Demo 5.1 and TRL6 for all other demos) and WP5 objectives. This requires end-user feedback and a system that can be proven working under realistic circumstances, for example with real-world data and adapted to end users' knowledge level and routines. Since the demonstrations have partly different TRL targets, different end-users and purposes, the validation method needs to be adapted to each demonstration. This will be described more in each of the following demonstration chapters.

Common for all demonstrations is that they all use validation events, presented in Deliverable 2.4 “Demonstration strategy”, (see, FP1-MOTIONAL, 2024a), to validate the demonstrations in cooperation with experts and end-users. All demonstration use cases are performed during the validation events and thoroughly evaluated together with the end-users. The exact procedure is decided by each demonstrating partner and described in each demonstration chapter respectively.

# 7. Demo 5.1 – Cross-border scheduling

Demo 5.1 focuses on Technical Enabler 1, demonstrating an interface solution that connects with a centralized scheduling system (Path Coordination System - PCS). The PCS is responsible for distributing path requests to relevant CMS operators. The system operates through an iterative process designed to streamline cross-border train path planning:

1. **Request Distribution**: The PCS receives path requests and distributes them to the relevant CMS operators.
2. **CMS Processing**: Each CMS operator evaluates the request by analysing local timetable availability and TCRs. The operator then responds to the PCS with either a confirmation or a modified version of the requested path.
3. **Iterative Refinement**: By repeating this process across all interested systems, a complete train path is established across all CMS domains. This iterative approach significantly reduces disruptions, minimizes time spent on coordination, decreases the number of manual calls, and reduces errors.

The demonstration will take place in Mermec's laboratory, which hosts both a CMS simulator and a PCS simulator. The CMS will run the Albacina–Civitanova regional line infrastructure, from central Italy, using real timetable data.

Although the demonstration focuses on a regional line, the concept applies equally to cross-area and cross-border scheduling scenarios. The interface uses the standardized "PathRequest" message structure defined in the ERA technical document "TAF TSI Data and Message Model" (see, ERA, 2012) ensuring compatibility and scalability across different operational contexts.

The demonstration covers use case FP1-DEMO-5.1-UC-1 “CMS decision support to plan a cross-border path”, (see, FP1, 2024c).

## 7.1. Method and development for Demo 5.1

A simulated environment was used to carry out the demonstration. The simulated environment comprises two different types of applications: a CMS and a PCS. Both applications are built using C#/.NET and communicate via SignalR, a library for Microsoft ASP.NET that enables asynchronous notifications between the systems.

The PCS simulator provides a graphical user interface (GUI). Figure 7.1 displays the sent path requests, highlights the differences between the requests and the responses received from the CMS, and offers basic controls to operate its functions. To send new path requests, the PCS leverages a File watcher function that monitors an XML file containing the path request data. When the file is modified and saved, the PCS automatically sends the message to the interested CMS operators.

The path request messages conform to the "PathRequestMessage" schema defined in ERA (2012) standard, utilising the same XSD model as depicted in the diagram in Figure 7.2.

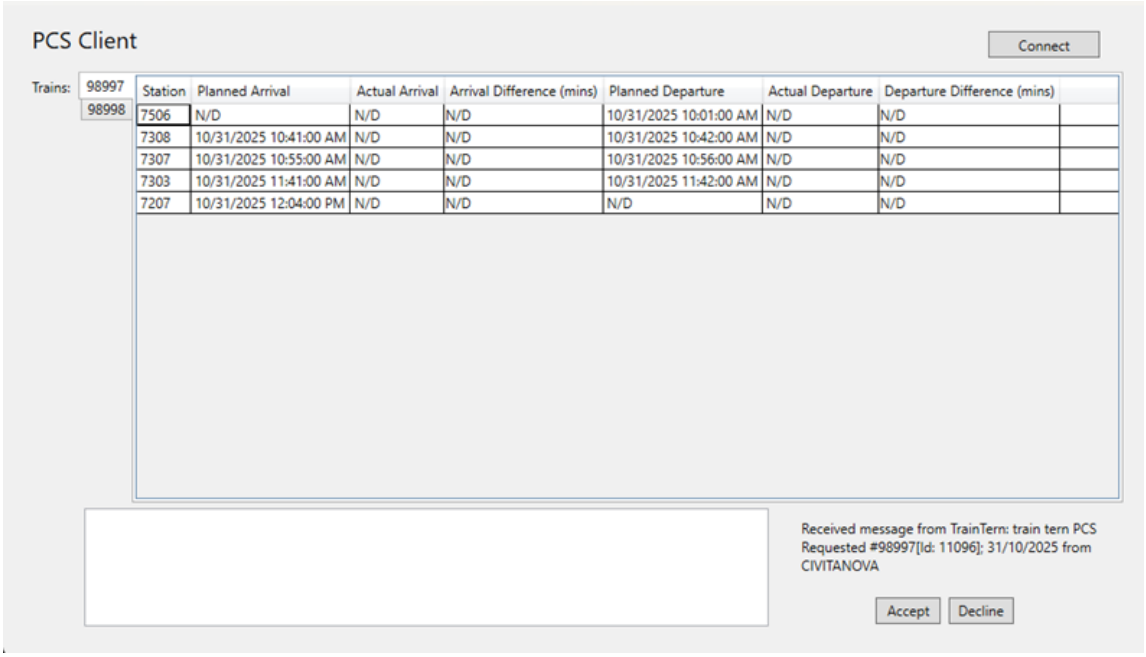



**Figure 7.1 – PCS simulator**

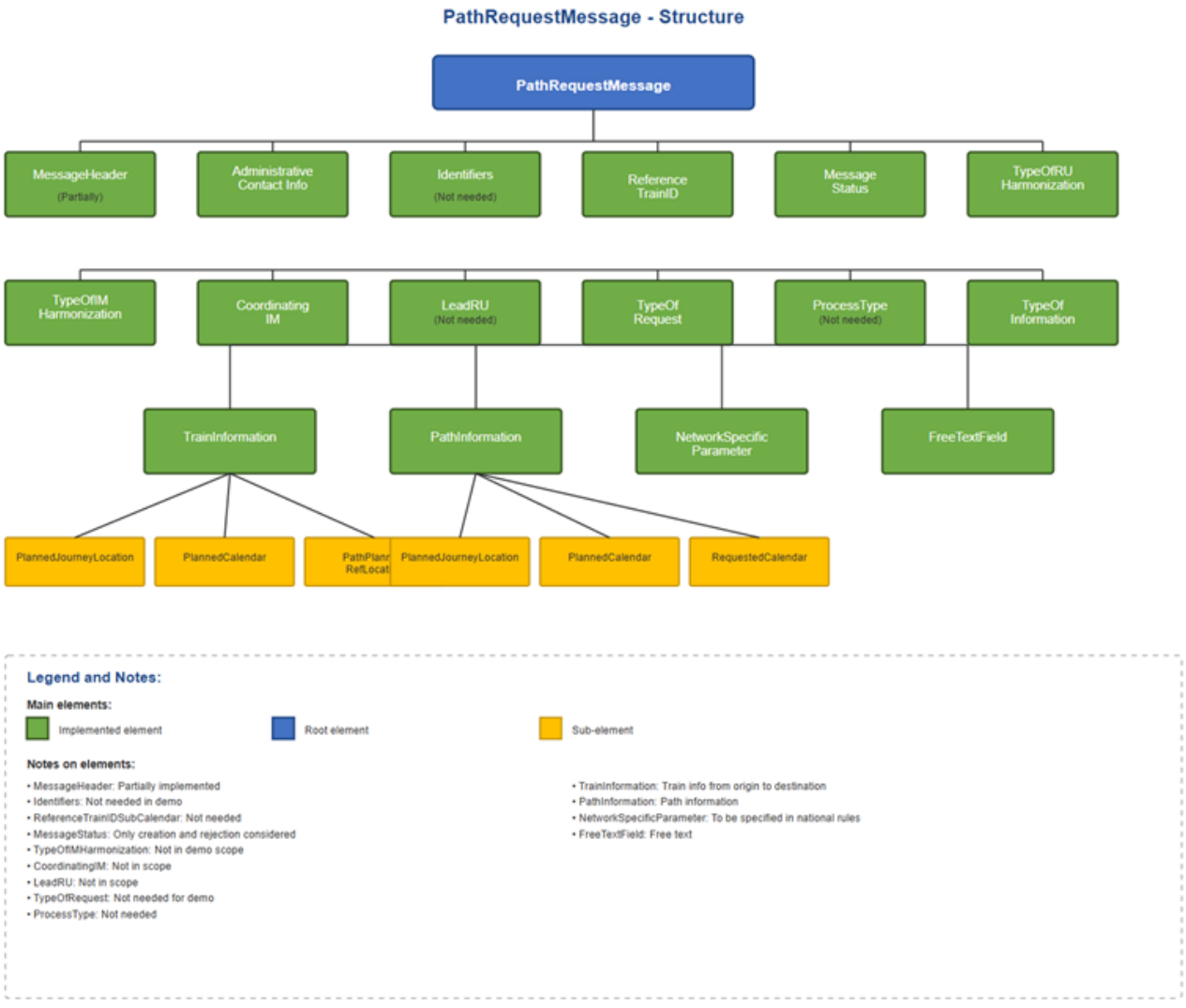



**Figure 7.2 – Path Request Message Structure**

When the CMS receives a new path request, the following sequence of events occurs:

- A notification appears on the Train Graph, displaying the basic information of the request
- The trains for the requested date are loaded into the system, if not already present.
- The new train is added to the database and marked as "toBeElaborated".
- The new train appears on the Train Graph displayed in a darker green colour, differentiated from existing trains (see, Figure 7.3).

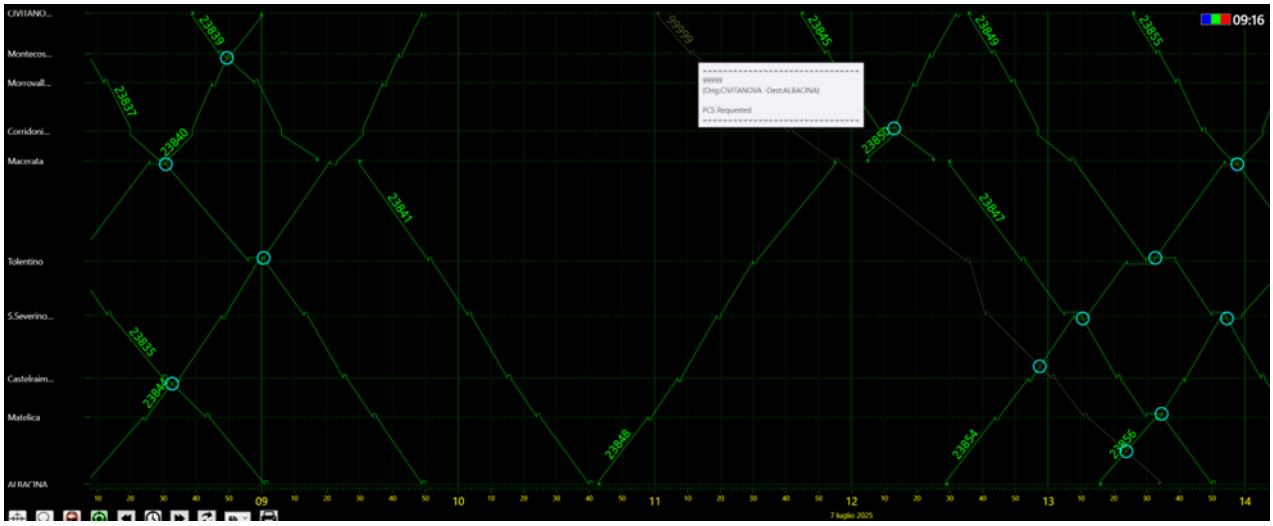



**Figure 7.3 – Path request received on the CMS**

Any conflicts identified during this process can be addressed by the capacity planner through harmonization. After making any necessary modifications, the capacity planner returns the path to the PCS (see, Figure 7.4).

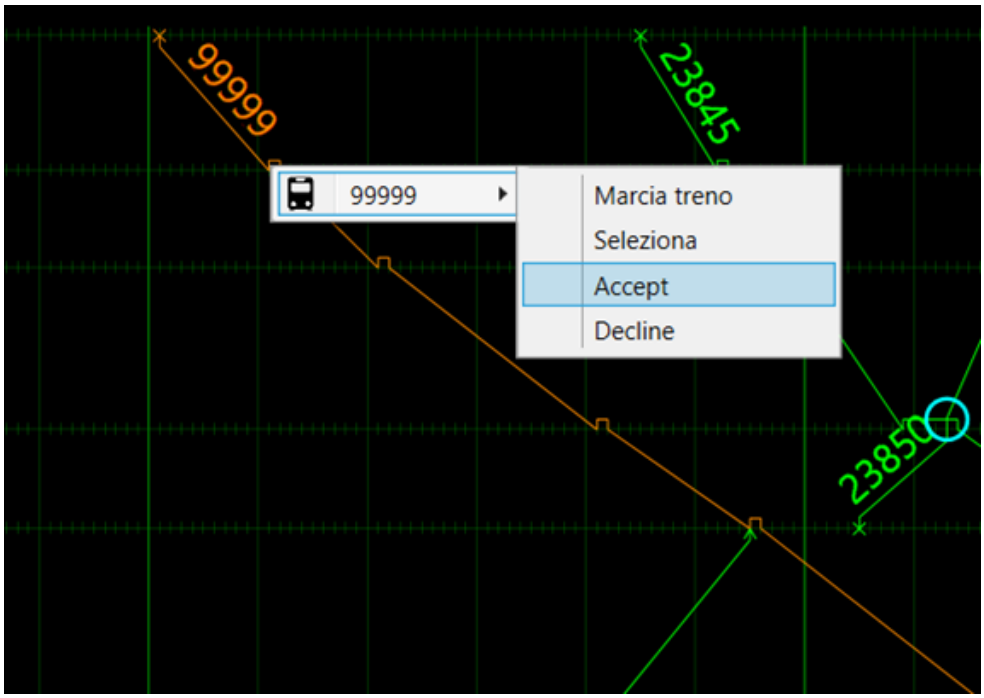



**Figure 7.4 – CMS operator options**

When the path is returned, it automatically changes state to "Draft", indicating a temporary status that is no longer editable. This prevents communication errors between the CMS and the PCS.

The PCS then displays the differences between the original and modified paths. Based on this comparison, the PCS operator can decide whether to accept or decline the offered path. Once the PCS confirms the path, the CMS implements the train in its timetable, reaching the final state: "proposed".

## 7.2. Demonstration planning of Demo 5.1

The activities performed during the **preparation phase** laid the foundation for the entire demonstration. The software and hardware architecture were designed and defined as described in the former section. A key aspect of the preparation was the decision to develop a PCS simulator, as direct integration with the existing operational PCS system was not feasible. The simulator was designed to replicate the behaviour of a real PCS, leveraging the same PathRequestMessage schema defined in the ERA (2012) standard. The use cases to be demonstrated were selected and documented, covering path request submission, acceptance, rejection with motivational notes, and the modification workflow. The necessary data to perform the demonstration was gathered, including the infrastructure model and timetable data for the Civitanova–Albacina line, a single-track regional railway in central Italy, which is represented in Figure 7.5.




**Figure 7.5 – Civitanova–Albacina line**

During the **implementation phase**, all components were gathered and assembled following the design patterns and architecture defined during the preparation phase. The PCS simulator was developed in C#/.NET and equipped with a graphical user interface allowing operators to send path requests, monitor their status, and review any differences between the original request and the response received from the CMS. Path requests are submitted via a file watcher function that monitors an XML file containing the path request data, automatically triggering the message to the CMS upon saving. The CMS was extended with a dedicated interface to receive incoming path requests, display them on the Train Graph in a temporary state, and notify the operator of new incoming requests. Communication between the two systems was implemented using SignalR, enabling asynchronous real-time notifications. Stable builds were deployed iteratively, with bugs identified and resolved throughout the process.

The **execution phase** consisted of running the defined use cases in a controlled laboratory environment. The PCS simulator was used to submit path requests to the CMS, triggering the full interaction workflow. Upon receiving a request, the CMS automatically loaded the trains for the requested date, added the new train to the timetable in a temporary state, and notified the operator via the Train Graph. The operator then evaluated the request, navigating to the relevant date and assessing any conflicts with existing paths. The three main decision scenarios were executed: acceptance, where the path was confirmed and immediately implemented; rejection, where a negative response with explanatory notes was sent back to the PCS; and modification, where the path was adjusted to resolve conflicts, placed in a draft state to ensure consistency between the two systems, and returned to the PCS for final approval or rejection.

The **evaluation phase** focused on assessing the results obtained during the execution phase against the expected outcomes defined in the test plan. The correctness and completeness of the message exchange between the PCS simulator and the CMS were verified across all use case scenarios. Particular attention was given to the consistency of the path states throughout the workflow — from the initial temporary state upon reception, through the draft state during modification, to the final implemented state upon confirmation. The usability of the operator interface was also assessed, evaluating the clarity of the notifications, the ease of navigation to the requested date, and the overall effectiveness of the decision-making workflow.

## 7.3. TRL validation of Demo 5.1

The demonstration targets TRL 5. To achieve this, the demonstration utilizes a real capacity plan with its associated timetable and an accurate representation of the Albacina–Civitanova line, provided as an XML file containing the static railway infrastructure data.

The validation event has been recorded for documentation and comprehend different test cases extracted from the addressed use cases. The UC/TC are presented in Tables 7.1 and 7.2.

**Table 7.1 – Use case**

| FP1-DEMO-5.1-UC-1 — CMS decision support to plan a cross-border track | |
|---|---|
| **ID** | FP1-DEMO-5.1-UC-1 |
| **Name** | CMS decision support to plan a cross-border track |
| **Description** | The CMS Operator or an Applicant makes a cross-border trace request. All CMSs involved harmonize the final time by evaluating their local availability and TCRs. |
| **Technical enabler(s)** | TE1 — European cross-border scheduling with international train path planning |
| **Stakeholder** | CMS Operator / Applicant |
| **Objective** | Get a conflict-free cross-border path inserted into the CMS timetable. |
| **Demonstration requirements** | CMS connected to a PCS; PCS-compliant infrastructure macro configuration. |
| **FP1 components** | CMS-PCS interface, CMS-PCS user interface, Event Logger. |
| **Other components** | PCS (Orchestrator), Prediction and Conflict Detection/Resolution Module |
| **Demonstration location** | Virtual: regional context on a line agreed with RFI. |
| **Storyboard** | 1. The CMS receives a trace processing request from the PCS. 1a. The CMS integrates the track. 1b. The Operator resolves conflicts. 1c. The CMS produces a harmonized track. 1d. If integrated, send draft confirmation; otherwise refuse. 2. The CMS receives track confirmation: it updates and confirms. 3. The CMS receives deletion: removes draft and sends rejection. |

**Table 7.2 – Test Plan**

| TC ID | Title | UC of ref. | Priorities | Type |
|---|---|---|---|---|
| TC-05.01 | Receipt of trace request and integration | UC-1 | High | Functional |
| TC-05.02 | Conflict resolution and outline draft confirmation | UC-1 | High | Functional |
| TC-05.03 | Final confirmation of the trace | UC-1 | High | End-to-End |
| TC-05.04 | Deletion/rejection of a track | UC-1 | High | Functional |
| TC-05.05 | Track rejection due to local unavailability | UC-1 | Medium | Functional |

| TC-05.01: Receiving Path Request and Integration | | | |
|---|---|---|---|
| **Description:** Verifies that the CMS correctly receives a trace request from the PCS and integrates it into the schedule. | | **Pre-conditions:** CMS connected to the PCS; macro infrastructure configured. TG loaded with trains' timetable. | **UC:** UC-1 |
| **#** | **Action** | **Expected result** | **Outcome** |

| | | | |
|---|---|---|---|
| 1 | From the PCS, submit a cross-border track processing request. | The CMS receives the request; The dossier appears in the interface. | *Successful. Problem: If the trace is re-edited and resubmitted, the PCS reports it as a delay* |
| 2 | Verify that the CMS integrates the path into the existing timetable. | The track is entered and displayed in the CMS timetable. | *Successful.* |
| 3 | Check for any conflicts. | The CMS reports conflicts if any. | *Successful.* |

| **TC-05.02: Conflict Resolution and Track Draft Confirmation** | | | |
|---|---|---|---|
| **Description: Verifies** that the CMS operator can resolve conflicts and confirm the draft trace. | | **Pre-conditions:** Trace request received; Track saved as draft (dark green); conflict(s) detected. | **UC:** UC-1 |
| **#** | **Action** | **Expected result** | **Outcome** |
| 1 | The CMS Operator reviews the reported conflicts. | Conflicts are visible with details. | *Successful* |
| 2 | The Operator resolves conflicts. | The track is harmonized with the timetable. | *Successful* |
| 3 | The CMS produces the draft harmonized track. | The draft is generated. | *Successful* |
| 4 | Send draft confirmation to the PCS. | The PCS receives confirmation of the draft track. | *Successful* |

| **TC-05.03: Final Track Confirmation** | | | |
|---|---|---|---|
| **Description:** Verifies the final confirmation flow of the trace from the PCS to the CMS. | | **Pre-conditions:** Draft outline confirmed and sent to the PCS. | **UC:** UC-1 |
| **#** | **Action** | **Expected result** | **Outcome** |
| 1 | From the PCS, send the final confirmation of the track to the CMS. | The CMS receives the confirmation. | *Successful. Note: The final confirmation has a timer of 60 seconds from receipt.* |
| 2 | Verify that the CMS updates the track. | The track changes from "draft" to "confirmed" status. | *Successful.* |
| 3 | Verify that the confirmation message has been sent by the CMS. | The CMS sends track confirmation to the PCS. A message appears on the PCS. | *Successful.* |
| 4 | Check that the path is integrated into the final timetable. | The track is visible as confirmed in the CMS timetable. | *Successful* |

| **TC-05.04: Deletion/Rejection of a Track** |
|---|

| **Description: Checks** the flow of deletion or rejection of a track. | | **Pre-conditions:** The CMS receives a track from the PCS. | **UC:** UC-1 |
|---|---|---|---|
| **#** | **Action** | **Expected result** | **Outcome** |
| 2 | On the CMS, edit the received track (e.g. insert a delay) | The track is changed | *Successful.* |
| 3 | From the CMS send the modified track to the PCS | The PCS receives the track | *Successful.* |
| 4 | From the PCS rejects the modified track. | The CMS receives the rejection and deletes the previously modified track. | *Successful.* |

| **TC-05.05: Track Rejected Due to Local Unavailability** | | | |
|---|---|---|---|
| **Description: Checks** that the CMS can reject a track if it cannot be integrated. | | **Pre-conditions:** Track request received from the PCS; impossibility of integration (e.g., active TCR). | **UC:** UC-1 |
| **#** | **Action** | **Expected result** | **Outcome** |
| 1 | Receive a track request in a slot with TCR active. | The CMS detects the impossibility of integration. | *Successful.* |
| 2 | The CMS Operator decides to reject the track. | The decline option is available. | *Successful.* |
| 3 | Verify that the track rejection has been sent to the PCS. | The PCS receives the decline message. The train path is deleted from the train list. | *Successful.* |

## 7.4. Evaluation and results in Demo 5.1

All five test cases defined in the WP5 test plan were executed successfully, validating the full interaction workflow between the PCS simulator and the CMS across the use case FP1-DEMO-5.1-UC-1.

TC-05.01 confirmed that the CMS correctly receives path requests from the PCS and integrates them into the timetable, displaying the new train in the graphical timetable with a visual notification to the operator (see, Figure 7.6). A minor observation was noted regarding conflict detection: conflicts are only highlighted upon reloading the graphical timetable rather than immediately upon path insertion, an aspect identified for future improvement.

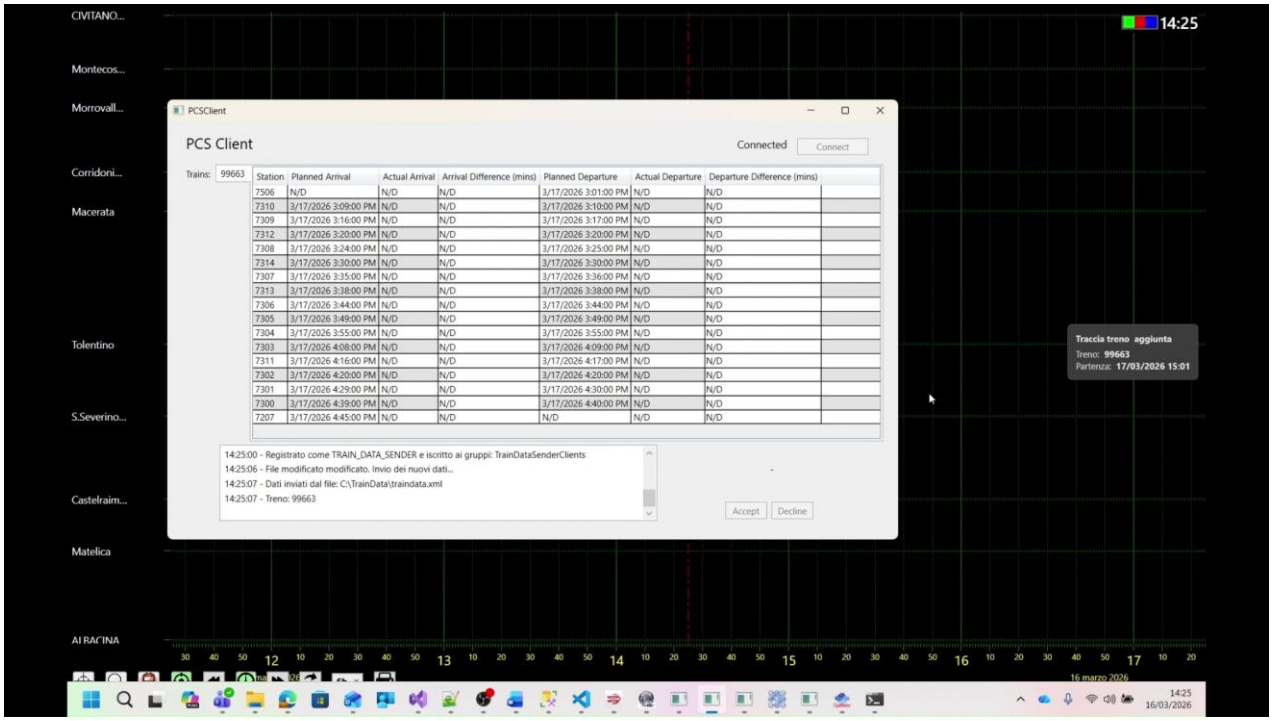



**Figure 7.6 – Path requested from the PCS; notification of the new path received on the CMS**

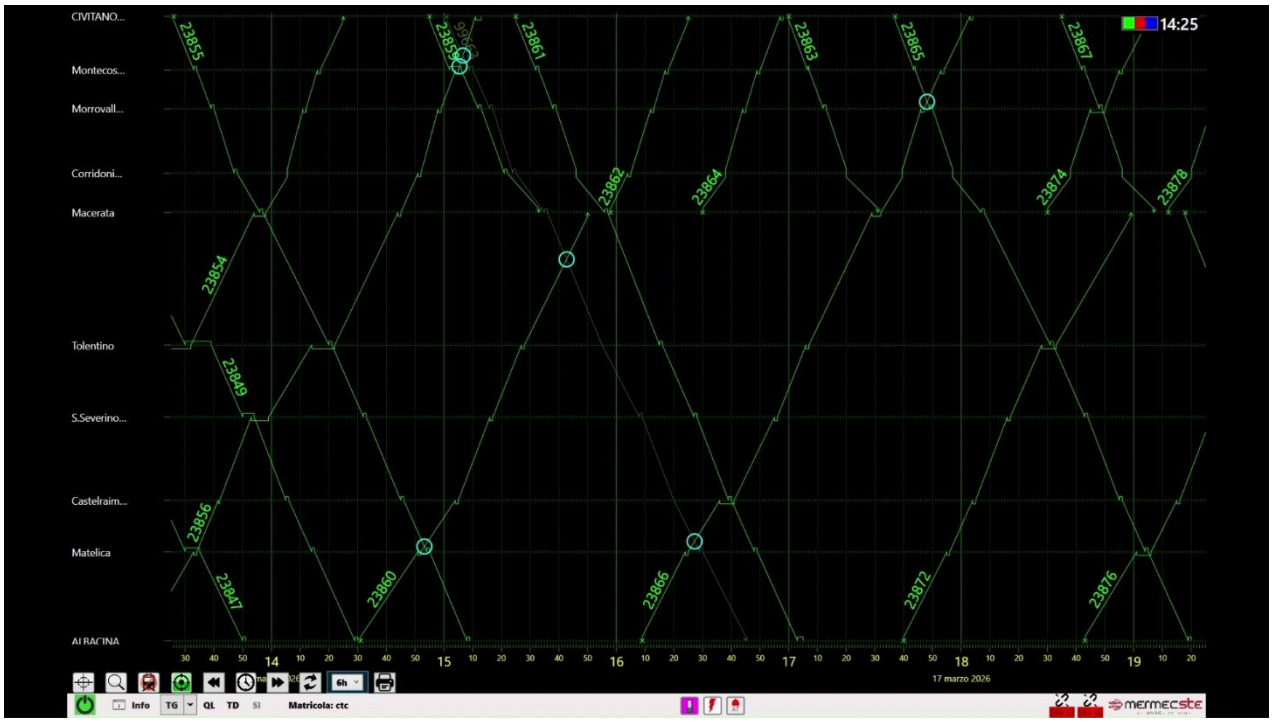



**Figure 7.7 – Temporary path implemented and represented in a darker green to differentiate it**

TC-05.02 verified the operator's ability to review and resolve conflicts on the received path (see, Figure 7.7), producing a harmonised draft track and successfully transmitting the draft confirmation to the PCS (see, Figure 7.8). TC-05.03 validated the final confirmation flow in its entirety: upon receiving the PCS confirmation, the CMS correctly transitions the track from draft to confirmed status and integrates it into the final timetable. A 60-second confirmation timer was observed to be functioning as designed (see, Figure 7.9).

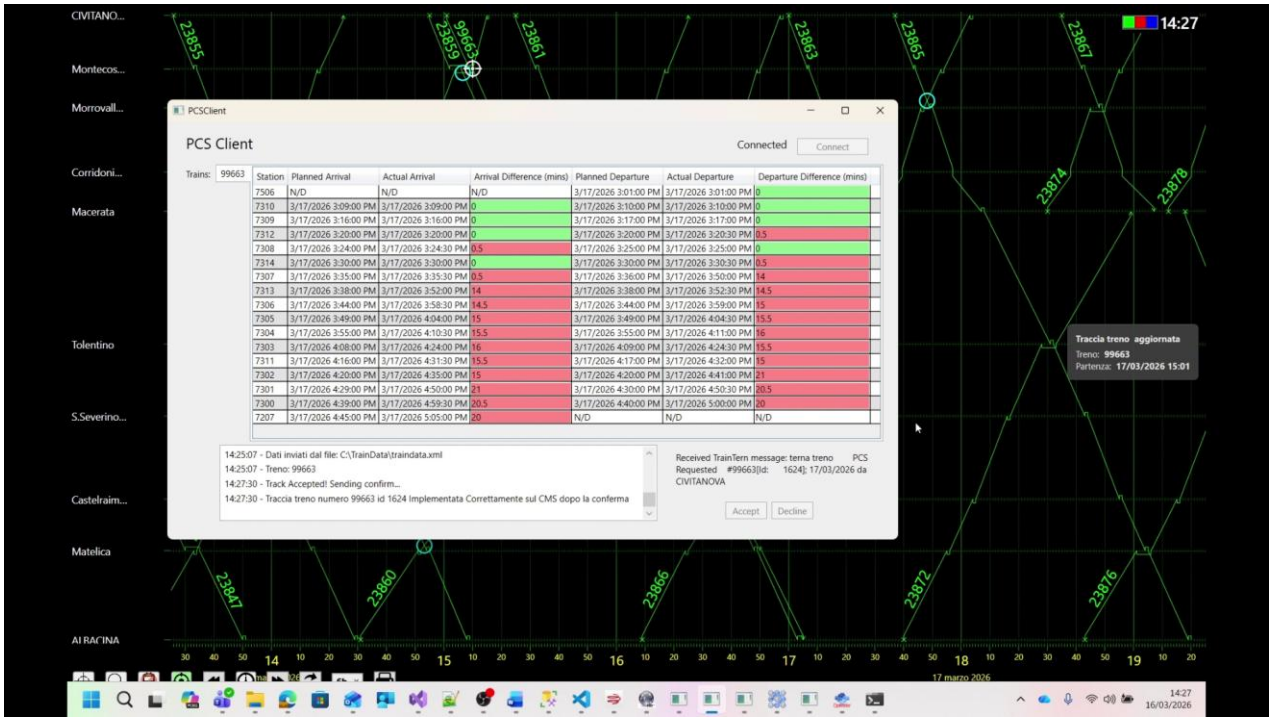



**Figure 7.8 – Path accepted after modifications**

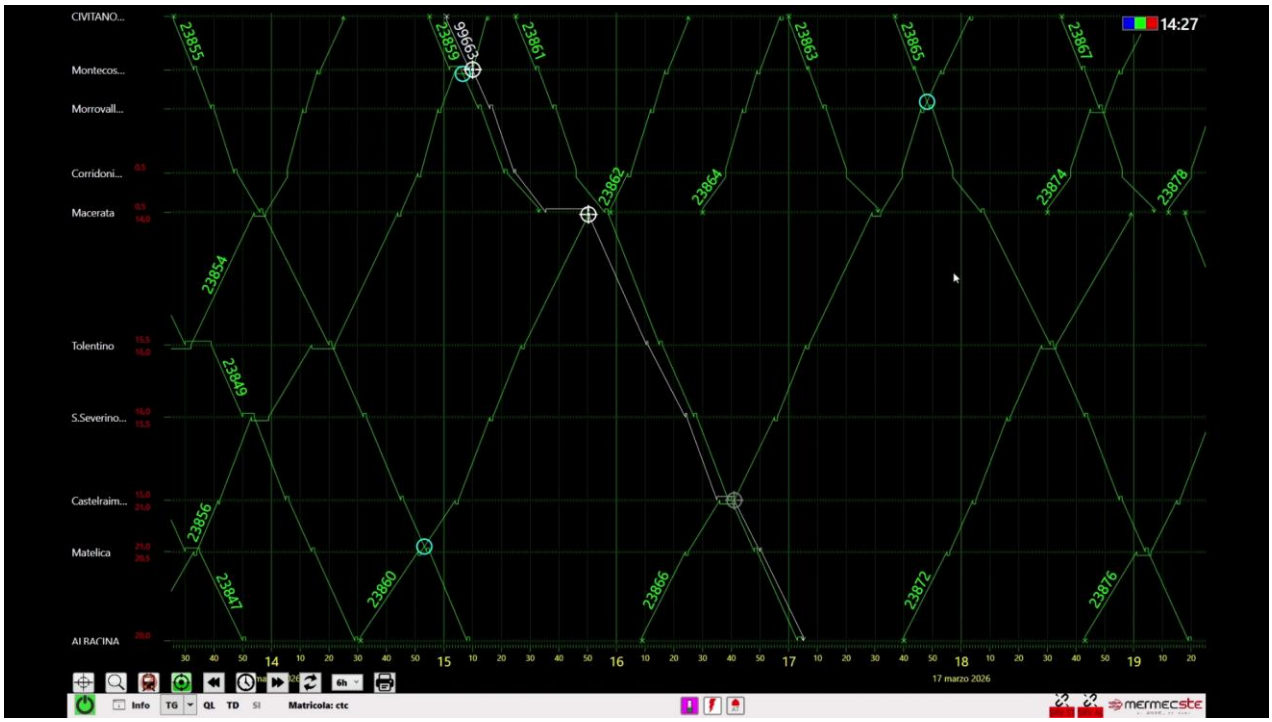



**Figure 7.9 – Path implemented and transformed to draft status to a definitive one.**

TC-05.04 and TC-05.05 covered the rejection and deletion scenarios. In TC-05.04, the full rejection flow was verified: a modified track sent to the PCS was rejected, and the CMS correctly removed the temporary path upon receiving the rejection response. In TC-05.05, the CMS successfully detected a local unavailability due to an active TCR and correctly rejected the incoming path request, with the rejection message properly received by the PCS (see, Figure 7.10).




```
2026-03-16 17:02:50,258 [25] INFO  SimulatorPCS - File edited. Sending path...
2026-03-16 17:02:50,269 [25] INFO  SimulatorPCS - Data sent from File: C:\TrainData\traindata.xml
2026-03-16 17:02:50,271 [25] INFO  SimulatorPCS - Train: 99663
2026-03-16 17:03:07,532 [56] INFO  SimulatorPCS - Train path number 99663 id 1633 rejected from CMS
```

**Figure 7.10 – Path gets declined from the operator**

**PCS log receiving the rejection from the CMS**

The results demonstrate that the developed solution effectively digitalises the path request coordination process between PCS and CMS operators, replacing what is currently a telephone-based, manual workflow with a structured, traceable, and fully automated message exchange. The system proved capable of handling the complete lifecycle of a path request — from reception and conflict resolution through to final confirmation or rejection — with clear operator feedback at each stage.

# 8. Demo 5.2 – International co-ordination of residual capacity in an early ad hoc stage

Today's capacity management relies on manual processing of capacity requests submitted from railway undertakings. The traffic planning is commonly divided in geographically separated construction areas, for which different planners often are responsible. This makes coordination and planning of long-distance and cross-border traffic, that spans over several construction areas, challenging. To simplify the coordination of residual capacity during the ad hoc planning stage, this demonstration aims to compute and visualise the remaining residual capacity in the graphical timetable for the planner. This makes it easier to coordinate ad hoc capacity requests that pass through different construction areas or involve multiple infrastructure managers. By presenting a set of feasible train path alternatives, the developed methods also reduce the planners need for manual "trial and error" in order to find available capacity, while preserving the decision making in the hands of the planner.

The demonstration consists of three use cases. In Use Case 1 (UC-FP1-WP3-7), a traffic planner wants to visualise residual capacity to schedule a cross-border train path request, given that the existing traffic cannot be adjusted. In Use Case 2 (UC-FP1-WP3-8), a traffic planner wants to visualise residual capacity to schedule a cross-border train path request, with the difference that existing trains may now be slightly adjusted. In Use Case 3 (UC-FP1-WP3-9), a traffic planner has found one or several train path alternatives (based on the residual capacity search carried out in one of the previous use cases) and simulates them to evaluate their train path robustness before making the final decision. Detailed descriptions are found in Deliverable D4.1, (see, FP1-MOTIONAL, 2024c).

## 8.1. Method and development for Demo 5.2

This demonstration addresses the problem of finding residual capacity in an existing timetable. The term residual capacity refers to the capacity that has not been allocated in the annual capacity allocation process (or at an earlier stage of the ad hoc stage). The concept differs from the UIC 406 timetable compression method, outlined in UIC Leaflet 406, see UIC (2013), in that instead of computing the remaining capacity based on compressing the timetable (i.e., pushing all scheduled trains as close together as possible with respect to constraints from signalling and operational regulations), continuous segments in which new trains can be scheduled are computed. For a given train path request, the found residual capacity segments show the timetable planner how the train path can be scheduled, which then simplifies the capacity allocation. An example a residual capacity segment is shown in Figure 8.1.

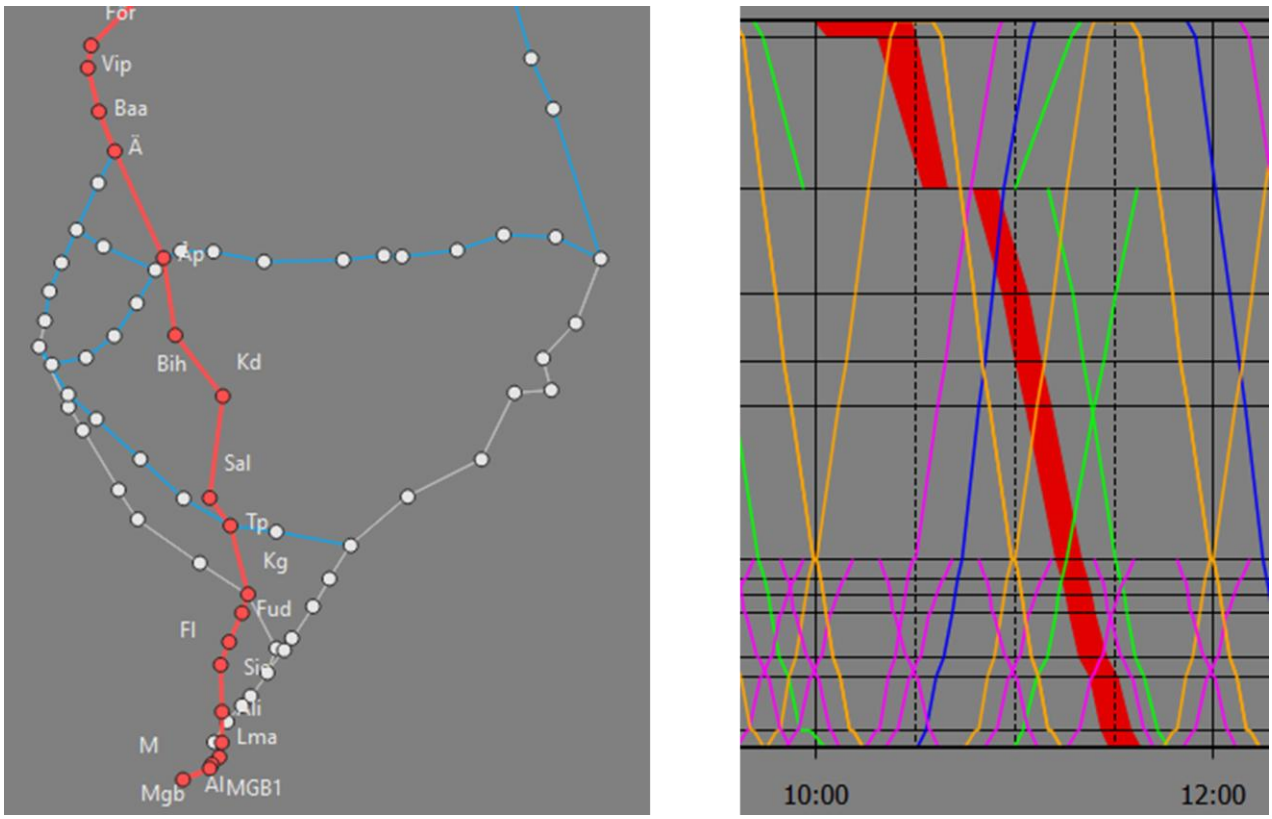



**Figure 8.1 – Illustration of residual capacity. The left figure shows a requested station sequence, and the right figure shows a residual capacity segment (the red area)**

The residual capacity segments are computed based on pushing time windows through the timetable and branching whenever a conflicting train is detected. The input specified by the user is:

- Requested train type (which then defines the minimum running times at each line segment)
- Origin, destination, and a fixed sequence of intermediate stations
- Minimum and maximum dwell time
- Minimum and maximum running time supplements
- An arrival or departure time window at the origin station
- Optional time windows at intermediate station, or the destination

A screenshot from the dialog used to specify the train path request is shown in Figure 8.2. In addition to the requested user input, it is also assumed that a timetable is given in advance, that the sequence of stations is known, and that stations where stop and overtakes can be scheduled has already been defined.

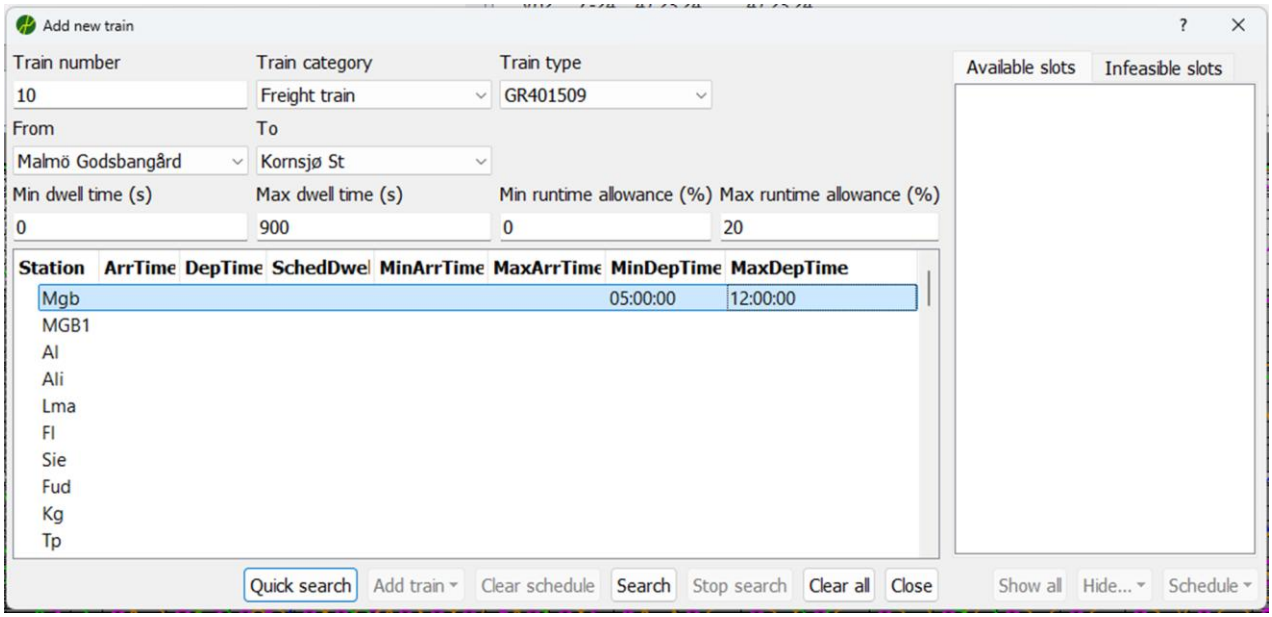



**Figure 8.2 – User input to the residual capacity search method**

Given the user input, the following steps are carried out to find residual capacity (illustrated in Figures 8.3 to 8.5:

1. Select the last departure time window for an unfinished capacity segment
2. Adjust its lower and upper bounds if partially conflicting with an existing train.
3. If a train is scheduled within the time window, split the time window such that the first part is conflict free and the second part is conflict free with respect to the previously conflicting train. Put the second part in a list of unfinished capacity segments.
4. Compute the arrival time window at the next station.
5. Adjust arrival time bounds if partially conflicting with other trains' arrival times.
6. Compute the next departure time window based on the current arrival time window, and maximum dwell time.
7. If the destination station has been reached, iterate through and update the arrival and departure times in a backward direction to ensure feasibility.
8. If the destination station has been reached, put the current capacity segment in the list of feasible capacity segments, otherwise put it in the list of unfinished capacity segments.
9. Return to step 1 if the list of unfinished capacity segments is not empty, else continue.

When the search has finished, or when the user interrupts it, the found residual capacity segments are shown in the graphical timetable.

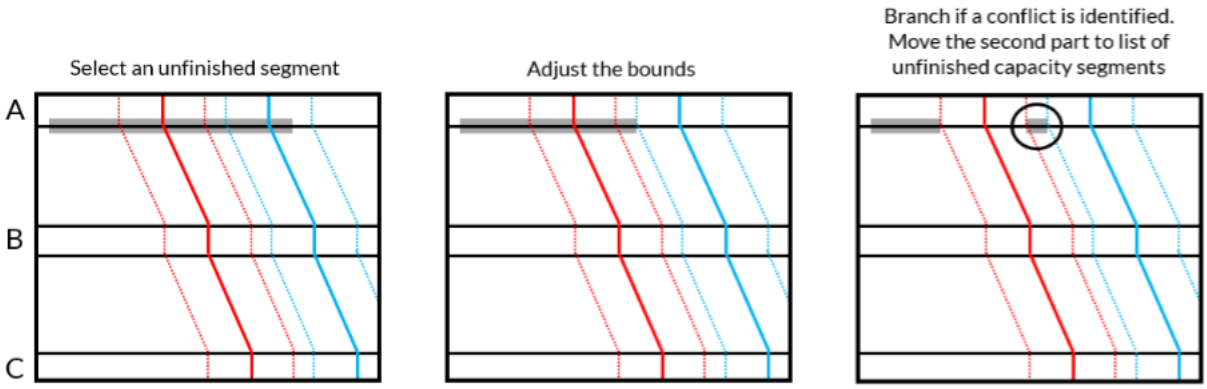



**Figure 8.3 – Steps 1-3 in the residual capacity search method**

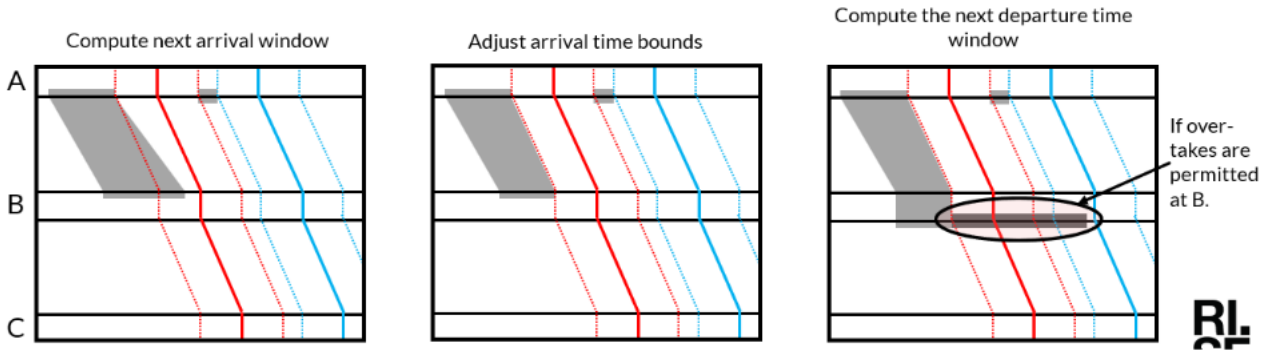



**Figure 8.4 – Steps 4-6 in the residual capacity search method**

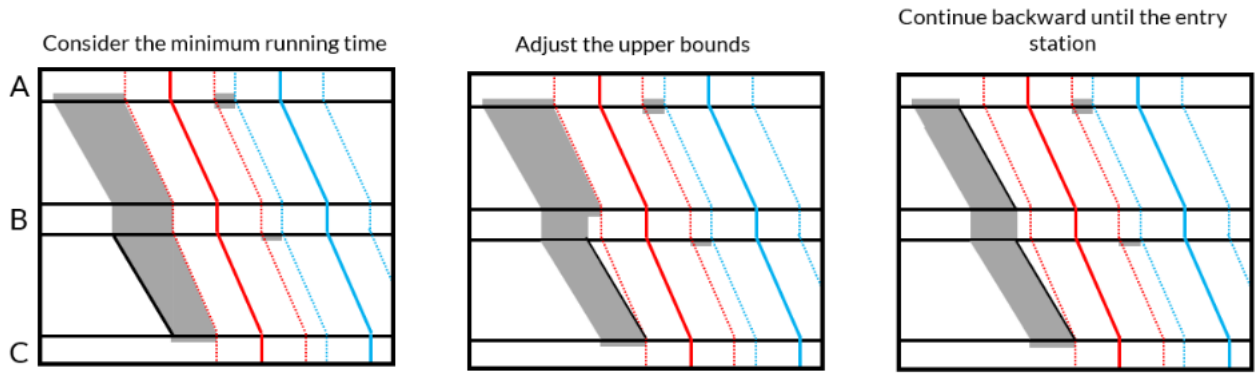



**Figure 8.5 – Steps 7-9 in the residual capacity search method. Adjust arrival and departure times by iterating backwards over the capacity segment**

The above-described branching-based method for identifying residual capacity is implemented for both single- and double-track sections. The main difference between single- and double-track sections lies in how the line segments between stations are occupied. For double-track sections, it is assumed that trains in the same direction must be separated by a given headway on the arrival and departure at each station, whereas train separation at single-track sections is ensured by letting trains occupy track-section entrance from both directions. In the case that two trains run in the same direction this becomes conservative since single-track sections may consist of multiple block sections and not just one block section. To overcome this, either pre-calculated headway requirements could be used, as for double-track sections, or block signals could be modelled as operational control points (timing points) without any features for train overtaking and passing.

Finally, to implement Use Case 2, in which the existing timetable is allowed to be slightly adjusted, a conflict resolution step is added to the capacity search. This step is triggered, whenever a conflict that leads to an infeasible capacity segment is identified. The conflict resolution is based on automatically defining a minimal optimization model that is only allowed to reschedule the conflicting train, while ensuring that it remains feasible with respect to all other trains. The optimization model is formulated to reschedule the individual arrival and departure times of the conflicting train. It is assumed that the individual arrival/departure times at most can deviate by $K_i$ time units from the given time (where $K_i > 0$ is a parameter that depends on the type of the specific event i). The model is formulated such that existing train orders cannot be changed, that all headway constraints must be satisfied, and that minimum running/dwell times are met. The objective is to minimise the deviation from the initial train path.

## 8.2. Demonstration planning of Demo 5.2

The demonstration planning is divided into four different phases: preparation phase, implementation phase, execution phase and evaluation phase.

In the **preparation phase**, plans for the demonstration, including validation and dissemination events, were made. The plan was to have the validation event at Trafikverket office in March 2026. End-users present for the validation should be timetable planners at IM Trafikverket. Outcomes of the demonstration were planned to be solution time compared to human planner, punctuality and train travel time. The plan was to discuss the functionality of the method; how useful such a support tool is for the planners and what can be improved.

In the **implementation phase**, the validation event was planned in detail. For example, both software and hardware (laptops) required were tested and validated. The method for finding residual capacity was implemented in the EFFÅ timetable optimization demonstrator where development originally started in a Swedish research project named FlexÅter2. In parallel with method implementation, data was collected, processed and validated. Several iterative meetings were held between demo developers and stakeholders at Trafikverket to improve the method and develop test scenarios to be prepared before the event. Validation tests were made to ensure that the method worked properly. The selected scenarios were also run before to collect the necessary data to be presented during the event. To capture the planners' opinions, a questionnaire and interview questions were prepared.

In the **execution phase**, the validation event was held at Trafikverket office in Solna. The event was organized together with Demo 7.5 since they both target the same end-users. Five timetable planners and two system developers from Trafikverket were present. During the event, the developed method was presented. The planners could try different scenarios and compare KPIs. Discussions were held throughout the event and in the end, the planners filled in a questionnaire.

In the **evaluation phase**, the results from the validation event were processed and analysed. The result was presented at the dissemination event "Cross-border planning" in Solna, Sweden, on the 13th of May 2026, and at the Swedish event "KAJT vårseminarium" on the 7th of May 2026.

## 8.3. TRL validation of Demo 5.2

This demo should reach TRL 6. Since the use cases mostly have focused on method development, the TRL definition for method/algorithm development is used. This means that a functional version of the method should be demonstrated for selected end-users on real-world cases based on historical and/or production data. Given the above interpretation of TRL 6, the TRL was validated as follows.

A validation event took place at Trafikverket the 2nd of March 2026. At the event, five timetable planners and two system developers from Trafikverket were present. Figure 8.6 shows a picture from the event. The timetable planners are suitable end-users, since they are working daily with changing and adding train paths in the annual timetable. We can assume that their feedback is sufficient to validate the developments.



**Figure 8.6 – Validation event for Demo 5.2 where five timetable planners validated the results**

At the validation event, the developed method was demonstrated. As a real-world test scenario, the infrastructure and timetable between Malmö freight yard (Sweden) and Alnabru freight yard (Norway) was considered. The infrastructure and timetable data was extracted from Trafikverket's national microscopic simulation model and corresponding data from the Norwegian infrastructure manager (Jernbanedirektoratet), which is up to date with the real-world infrastructure. The timetable used was the real-world timetable from 2022, also provided by Trafikverket and Jernbanedirektoratet.

At the event, a set of fictive train path requests was used to demonstrate how the developed method can be used to simplify ad hoc planning. During the validation event, the end-users were active in testing the algorithm. They gave feedback and reasoned about the results and decisions. In the end, they answered a questionnaire. Details from the evaluation are presented in the next chapter.

All three use cases were demonstrated for the part of the Scandinavian-Mediterranean Corridor (ScanMed)that runs between Malmö freight yard and Alnabru freight yard (Sweden–Norway). The base timetable was selected from the 2022 timetable for two consecutive dates. The tool requires a RailSys model (infrastructure, timetable etc.) since the routines for importing the necessary data required by the tool are made for RailSys data formats. RailSys is a microscopic planning and simulation tool for rail traffic.

On the Swedish side, the national RailSys model maintained by Trafikverket, gives most of the input data required, both regarding infrastructure and timetable. For the Norwegian side, a RailSys model has been created. The infrastructure data was available in railML format. RailSys does not support railML, therefore a framework with conversion scripts were created with the purpose of first reading in railML infrastructure data for processing and later be able to write infrastructure data in a RailSys internal XML format. To get a fully functional infrastructure model in RailSys, actions are also required in the RailSys tool itsel, mainly to connect the different lines which make up the section from the Swedish–Norwegian border at Kornsjö to Alnabru freight yard. Following this, the Norwegian infrastructure model was connected to the Swedish 2022 infrastructure model.

Timetable data for the Norwegian side was also provided in railML format. Similarly to the infrastructure handling, conversion scripts were created to be able to import a railML format timetable into the RailSys model. After import and additional handling in RailSys, trains crossing the border were merged. Infrastructure and timetable data from the RailSys model is then used as base input in the “other model”.

## 8.4. Evaluation and results in Demo 5.2

The validation was carried out at Trafikverket with five timetable planners and two system developers present. During the event, the tool was demonstrated on fictive train path requests based on real infrastructure and timetable data for the Malmö–Alnabru corridor, discussed the results together with the researchers, and completed a questionnaire at the end of the session. Overall, the questionnaire responses indicate that the planners were positive to the demonstrator, particularly regarding the graphical presentation of alternatives and the potential for a more fully developed tool to support and speed up the ad hoc planning process.

The validation event demonstrated that the EFFÅ demonstrator can support timetable planners in identifying residual capacity in a given timetable. It demonstrated how the tool can be used to find capacity by either searching along the full corridor or by dividing the corridor into subsections and solve them in parallel. The benefit of the full-corridor approach is that it provides capacity segments that can directly be transformed into train paths, while the subsection-based approach offers shorter computation times and greater flexibility, for example by allowing different trains characteristics along the journey and more tailored constraints on dwell-times within and between

subsections. It was also demonstrated that the tool can be used to generate alternative train paths too and that the alternative train paths can be evaluated using simulation within the tool, or an external simulation software, to support the planners' decision making.

Figure 8.7 shows a screenshot of the tool as demonstrated for the planners. The figure shows the main view of the tool, which is centred around a table that shows all trains, a table that shows the schedule for a selected train, a graphical timetable, and a network view, in which the user selects the desired line to visualise in the graphical timetable. The selected sequence of stations also determines which route in the network the capacity search for will consider. Finally, the figure shows the window for entering parameters to initiate a residual capacity search to insert a new train to the timetable.

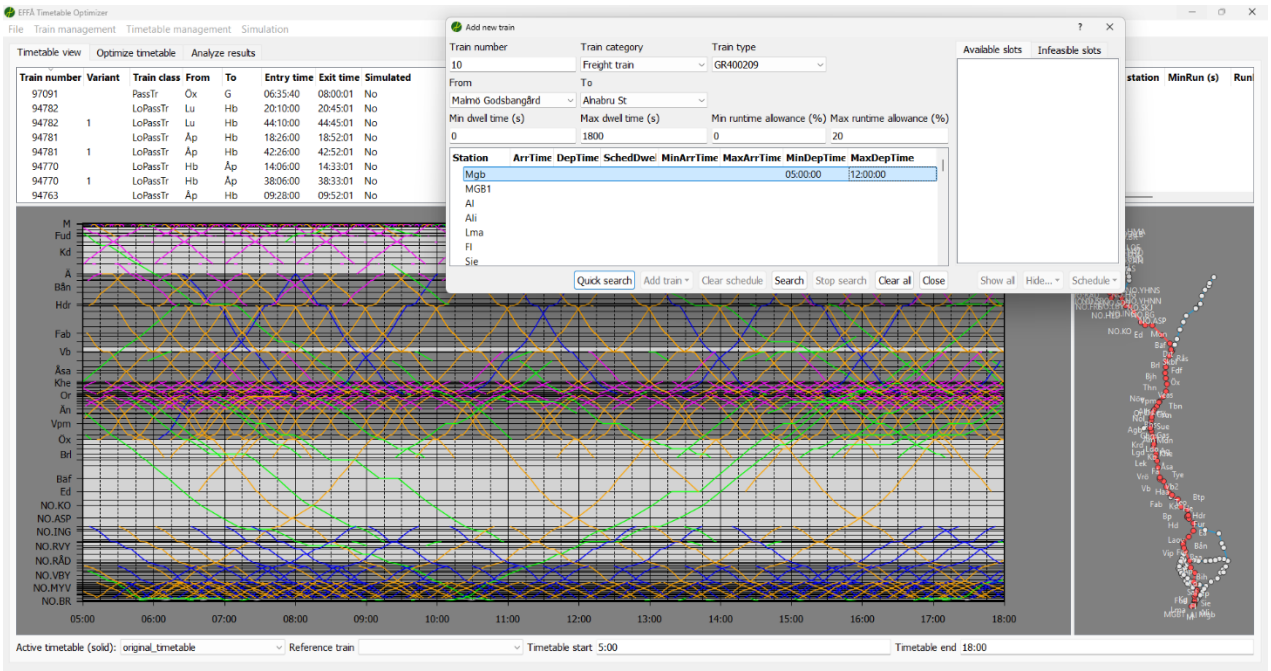



**Figure 8.7 – Screenshot of the main planning view in EFFÅ**

The result of the capacity search is shown in Figure 8.8. This figure shows a dialog window that informs the user that 78 potential train path slots (capacity segments) were found. The capacity segments are shown directly in the graphical timetable. As can be seen, there are two types of capacity segments: red capacity segments, which does not require any modifications of the already planned traffic; and purple capacity segments, which only are feasible if at least one train has to be adjusted (the necessary modifications are shown in the graphical timetable). Analysis of individual capacity segments is possible by selecting one item in the list of "available slots" to the right. When a single capacity segment is selected the user has the possibility to create train path alternatives using an automatic scheduling function. These train paths can be saved in temporary timetable variants. This allows the user to simulate the resulting timetable variants within the tool or using external simulation tools to analyse the robustness of the solutions before making the final decision.

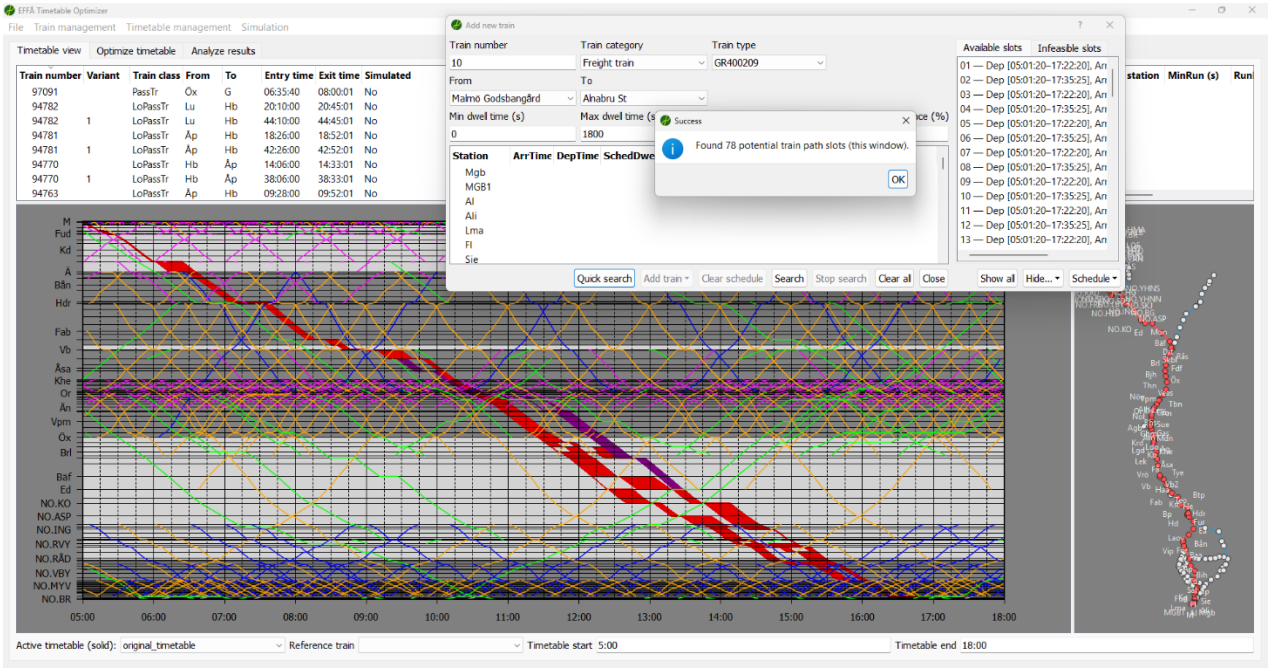



**Figure 8.8 – Capacity segments found by the algorithm**

The developed tool was evaluated at the end of the validation event using a questionnaire. All five timetable planners that participated in the validation event completed the questionnaire. The questions and responses are shown in Table 8.1. As can be seen, the respondents where in general positive to the tool. It was considered easy to work with the graph to select a train path solution, and a fully developed tool was expected meet their needs and allow to speed up the ad hoc planning process.

**Table 8.1 – Questionnaire and distribution of responses**

| Question | Not at all | | | Very well |
|---|---|---|---|---|
| 1. How well do you understand the problem and which parameters that can be edited? | | 2 | 3 | |
| 2. How easy is it to use the graph to select at train path solution? | | | 4 | 1 |
| 3. How useful is the iterative method to edit and test parameter values and run the model to find a good solution? | 1 | 2 | 1 | 1 |
| 4. How well does the tool fill your needs? | 2 | | 3 | |
| 5. How well do you think a fully developed tool could fill your needs and speed up the ad hoc process? | | | 3 | 2 |

The questionnaire also indicates the perceived usefulness and (probably) applicability of the current tool varied among the respondents. Question 3 shows a relatively even distribution from the second worse rating to the highest rating. One of the respondents also commented on

question 3 that “the alternatives are easy to understand but the tool is hard to use. Some information is missing, for example feasible track allocation.” Since it was the first time the tool was demonstrated for the planners, in combination with that the demonstrated workflow contained several decisions and some manual steps in the tool to combine the found solutions, it is possible that the tool seemed a bit difficult to use. In a further developed tool, additional steps to improve the user experience should also be taken.

In the questionnaire, Question 4 was also a bit of a divisor among the respondents. Two of the planners gave the second lowest rating on how well the tool fill their needs, while three of the planners gave the second highest rating. This could be due to that the participants had different roles and responsibilities in the planning process, and therefore not the same needs.

The discussion during the validation event highlighted several areas in which the demonstrator could create practical value in real-world planning. The planners noted that the tool is useful not only for ad hoc capacity allocation, but also for re-routing trains and for planning long routes that today are time-consuming to construct manually and often require several iterations before a feasible path is found (in some cases up to a full working day). With the developed tool, realistic test cases, spanning over several construction areas, could be solved in 10-30 minutes, including time for simulating generated alternatives. They also appreciated the visual representation of the graph and the feasible areas, which makes the alternatives easier to understand and discuss. These observations suggest that the demonstrator has clear potential to reduce manual trial-and-error work, improve transparency in planner decision-making, and support more efficient coordination of complex train paths over longer distances.

The feedback also pointed to several important development needs before the tool can be fully integrated into operational practice. One questionnaire comment noted that the tool needs to handle several TCRs in the network to become fully useful. In the discussion, the planners further highlighted the need to include feasible track allocation and station capacity, track lengths for overtaking and passing, restrictions related to train weight and loading gauge/profile, and constraints on the duration and location of breaks. It was also noted that time windows are not always used frequently in today’s requests. Put together, these comments provide several areas for future development toward a more operationally complete decision-support tool. Other areas that should be addressed in future work is to extend the method to reduce the need for specifying a fixed route through the network, as well as managing multi-track lines, as well as capacity constraints within stations (in particular large and complex stations).

# 9. Demo 5.3 – Interfaces for interaction with external national or central planning applications

Rail infrastructure capacity across Europe is finite and, in many critical regions, heavily contested. As demand grows and cross-border operations become increasingly common, multiple operators compete for access to the same tracks— often spanning national boundaries and multiple planning horizons.

The development for Demo 5.3 was based on the results of activities in Subtask 5.2.1, which aimed at achieving TRL 6. The Subtask 5.2.1 focuses on the development of demonstrators for interfaces that allow interaction with external national or central planning applications and allow to demonstrate cross-border planning, specifically including Short Term Timetable Planning and process improvement among actors.

The timeframes "X-8 and X-2" refer to requests made between 8 and 2 weeks before the start of the new timetable period (X), while "X-2 and X+12" covers requests from 2 weeks before up to 12 weeks after the timetable has commenced.

The development for Demo 5.3 covers the following WP 3 use cases:

- International late path request placed between X-8 and X-2 (UC-FP1-WP3-1)
- International path request placed after X-2 and before X+12 (UC-FP1-WP3-2)
- Showing and handling of impact of imported TCR (UC-FP1-WP3-3)

The demonstration is part of the group of demonstrations where the Alnabru (Norway) – Malmo (Sweden) corridor was selected. A corridor with more than six hundred kilometres of railway lines, partially shown in the Figure 9.1.

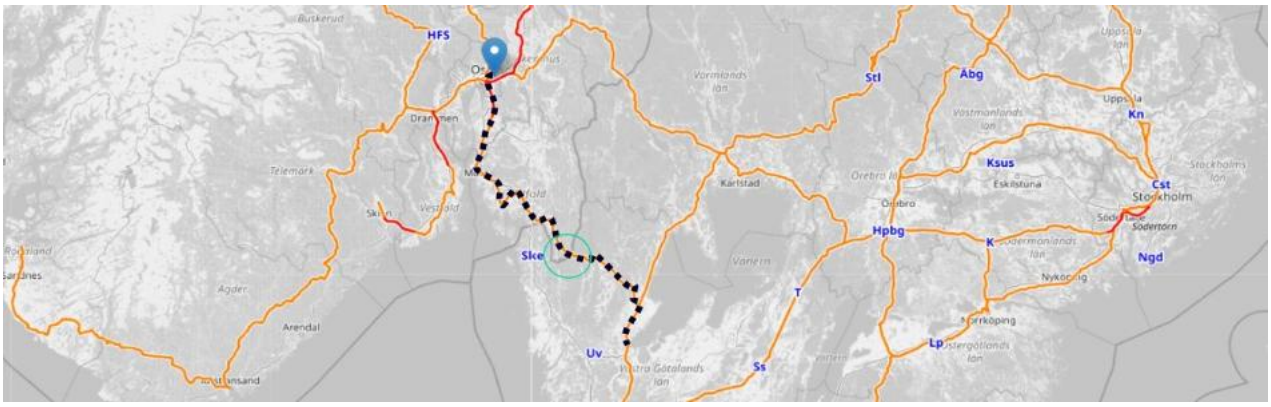



**Figure 9.1 – Cross-border railway line between Norway and Sweden**

## 9.1. Method and development for Demo 5.3

Path Coordination System (PCS) is a regional, web-based platform to coordinate international train path requests across European borders. PCS supports bi-directional, system-to-system data exchange with national CMS platforms. TPS.plan supports interfacing with RNE PCS via both the PCS Integration Platform (web services) and Telematics TSI CI.

A key focus of this development is to support enhanced cross-border planning, which is crucial for the facilitation of international rail traffic. Furthermore, the interfaces support long-term and short-term planning activities and bring significant process improvements among all involved actors in the rail planning ecosystem. This foundational work directly contributes to more effective and better coordinated planning cycles between different national CMS'.

In the Demo 5.3, the capacity management system (CMS) interacts with regional platforms for data exchange to enable planning of international paths in LTP and STP capacity planning and to receive TCRs, see Figure 9.2 (scope indicated in red color). For the technical communication with regional platforms of data exchange (PCS and TCR tool of RNE), the Common Interface provided by RNE is used along with Telematics TSI based communication protocol.

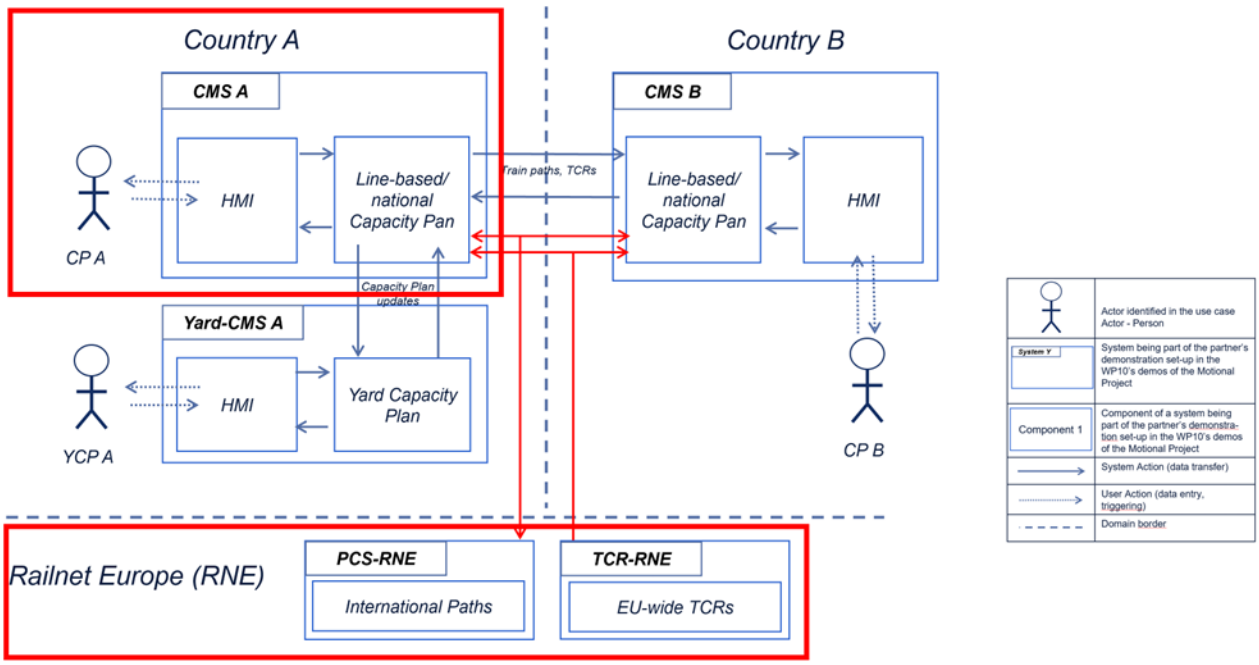



**Figure 9.2 – General system concept of Demo 5.3**

The scope of the functionality addressed by the demonstration follow the Use Cases and Requirements as described in 'Deliverable 4.1 Integration of Planning Systems' and is reflected by the following topics:

1. Receipt of path requests for international trains via the path coordination system PCS (RNE).
2. Submission of path offers for international trains via the path coordination system PCS (RNE) using the Common Interface.
3. Import of TCR received from an external system.
4. Visibility of foreign line section behind the border location and related capacity objects.
5. Set-up and sharing change scenarios ('sandboxes') in the national capacity plan with the neighboring IM/CMS.
6. Access rights in conjunction with capacity plan change scenarios ('sandboxes') shared with the neighboring IM/CMS for alignment on cross-border line sections.
7. Status transition of change scenarios ('sandboxes') shared with the neighboring IM/CMS for alignment on cross-border line sections.

The main components involved are the CMS and the PCS. The CMS exchanges messages with the PCS Capacity Broker (PCS CB) via the Common Interface (CI) using Telematics TSI messages as seen in Figure 9.3.

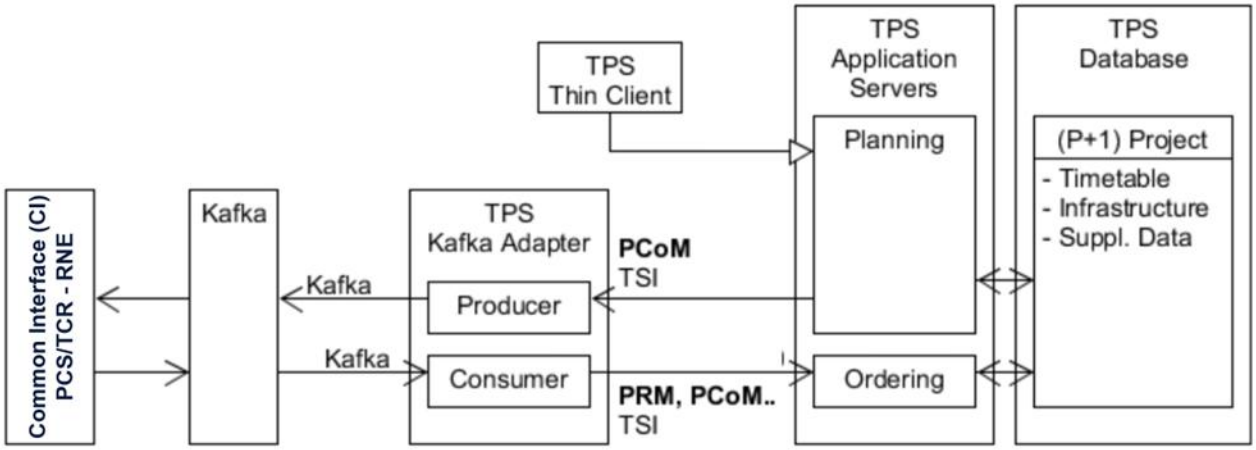



**Figure 9.3 – Architecture of Demo 5.3 PCS/TCR integration**

The following sections presents the breakdown of each component and its role.

**Common Interface PCS – RNE**

This component serves as a gateway for communication with RailNet Europe (RNE)'s PCS - Capacity Broker (PCS-CB) system. It is responsible for sending and receiving messages to and from PCS-RNE for International paths and TCR-RNE for EU-wide TCRs.

This is a critical external interface for Demo 5.3, directly addressing the need for interaction of central planning applications with PCS. This interface handles the Telematics TSI message format and is central to transmitting New Path Requests (NPR), Late Path Requests (LPR), and Ad-hoc Path Requests (AHPR) across national borders. It ensures that TPS can effectively communicate and exchange international train path information with other connected IMs and RUs.

**Asynchronous message broker**

We have implemented a high-throughput, distributed asynchronous message broker between the CI and the CMS. It ensures reliable and scalable data exchange. The use of the asynchronous message broker provides a resilient and decoupled communication channel. This is vital for handling the potentially high volume of capacity requests, especially in a cross-border context where different systems need to exchange information efficiently. It enables the seamless flow of information that underpins the vision of Demo 5.3.

**CMS Adapter**

The CMS Adapter is a TPS component which is responsible for translating messages between the destination system and the internal data structures and protocols of the CMS. TPS takes outgoing messages from the CMS (e.g., path requests generated by the 'Ordering' module) and publishes them to asynchronous message broker for transmission via the CI to PCS.
TPS also listens for incoming messages (e.g., capacity offers) and translate them into a format usable by the CMS.

**CMS Client**
This is the user interface through which timetable planners and other users interact with the CMS.

The user interface allows users to initiate and monitor path requests, view capacity information, and manage planning activities.

## 9.2. Demonstration planning of Demo 5.3

The Demo 5.3 plan is divided in four phases: Preparation, Implementation, Execution and Evaluation.

During **preparation phase** the technical and organisational initial activities for the demonstration were completed. The first activity included the specification and preparation of a testing environment. After the main components were deployed, the configurations of the CMS Adapter and connection to the CI was established.

The necessary infrastructure data model was prepared. In this case the preparation included the import and configuration of the infrastructure of Norway.

For the **implementation phase** it was considered that the CMS supports bi-directional system-to-system integration with the PCS for the exchange of information relating to international paths.

For purposes of this demonstration, TPS.plan, a product within the TPS suite of products offered by Hacon Siemens was used. TPS.plan supports bidirectional system-to-system integration with the RNE PCS via both the PCS Integration Platform and the Telematics TSI CI. Leveraging established Telematics TSI standards ensures that data shared across borders is consistent, machine-readable, and compatible with partner systems. This reduces integration complexity and supports interoperability at a European scale.

As international capacity management standards and processes continue to evolve, TPS.plan evolves with them — ensuring a smooth transition without disruption.

After the initial interface test was completed, more thorough testing validated that the CMS replied as expected, e.g., showing received requests for international train paths and allowing a user to make amendments to the planned train path using the CMS user interface.

During the **execution phase**, the planned test scenarios were executed. The pre-defined message templates in Telematics TSI format were edited to contain the necessary input data. The corresponding test results were captured in screen recordings and stored as evidence of the testing outcome.

During the **validation phase**, quantitative and qualitative feedback was collected during the validation event, using a questionnaire. The questionnaire was answered by the end-users participating in the event.

## 9.3. TRL validation of Demo 5.3

To conduct the tests, the test strategy is to focus on the requirements as well as on usability user friendliness of system functionality. These test procedures include:

- **Functional tests:** these are defined based on the specific Test Cases.
- **Feature testing**: In this phase, any modification being done (because of the functional tests) by the developers is tested to ensure the functionality is implemented correctly.

The overall test procedure is to implement in the defined Test Frameworks to:

- Verify, given an input, e.g., if a JSON message is correctly created with the correct format and expected information to be processed via the interfaces.
- Verify the result, e.g., messages received, GUI snapshots indicating sending or receipt of messages, showing changes in application GUI.

The objectives of the testing activities are:

- verifying that the requirements are met;
- evaluate results of other activities such as requirements, Use Cases, design and code (where applicable);
- find and prevent defects; and
- report the defects.

The verification of the defined use cases in the deliverable “Deliverable D4.1 Integration of Planning Systems” was done during the validation event that took place in Siemens Mobility Portugal office in Alfragide, Amadora, Portugal as seen in Figure 9.4. The event took place on April 15, 2026. For purposes of the validation, four end-users were present in the room with a background of time tabling, namely in the Portuguese railway infrastructure, for the national infrastructure manager. Besides them, two system engineers were also in the room, and more than six other project collaborators have joined remotely.

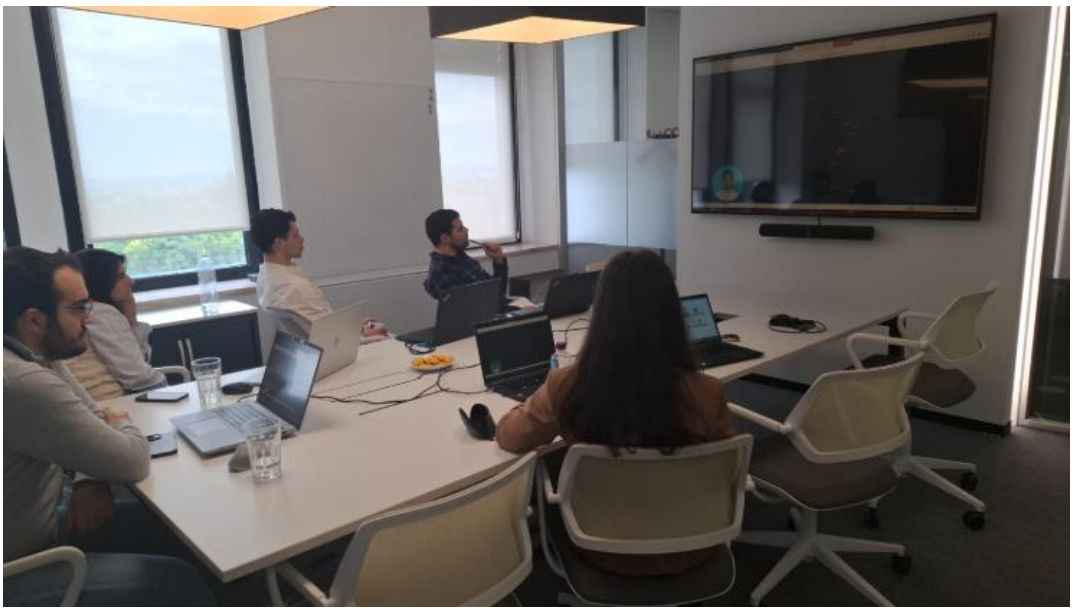


**Figure 9.4 – Validation event in Alfragide, Amadora**

Figure 9.4 shows a picture of the event at Siemens Mobility in Alfragide, Amadora, Portugal. The selected group of end-users have experience in timetabling activities with customers and have provided valuable feedback on the use cases that were demonstrated. They didn't have previous experience in the CMS platform that was used for the demonstration, and it was possible to validate all the developments and accomplished results.

As a closing activity of the validation event, quantitative and qualitative feedback was collected using a questionnaire. The questionnaire was answered by the end-users participating in the event. The questionnaire included the following questions:

1. Overall, how useful do you find the functionalities demonstrated today for the daily work of a timetable planner/dispatcher? Answer type: from '(1) Not at all useful' to '(5) Extremely useful'
2. How clear and easy to understand were the demonstration use cases presented today? Answer type: from '(1) Very unclear' to '(5) Very clear'
3. How well do you think the demonstrated processes address current challenges in managing railway capacity and planning? Answer type: from '(1) Not at all well' to '(5) Extremely well'
4. From all the functionalities demonstrated today, what was the most valuable aspect or feature you saw? Answer type: Open text
5. What is one area where you believe the demonstrated functionalities could be improved or need further development? Answer type: Open text
6. How do you envision these new functionalities integrating with your existing workflows or tools, and what potential challenges or benefits do you foresee? Answer type: Open text
7. Do you have any other comments or suggestions regarding the demonstrated functionalities, the overall approach to capacity management in TPS, or the workshop itself? Answer type: Open text

The questionnaire was anonymous and users were properly informed about that. The collected answers served to determine the perceived value of the demonstration as well as to capture recommendations for future developments and enhancements with the potential to further improve the solution. The questionnaire was distributed as a closing activity on the day of the validation event.

## 9.4. Evaluation and results in Demo 5.3

One of the main use cases presented in the validation event follows the different steps in order to create a train request. As a starting point, a late path request is sent to the CMS system using the testing platform of messages. The CMS receives the message and creates an order item for the train run in the state "Ready" as shown in Figure 9.5.

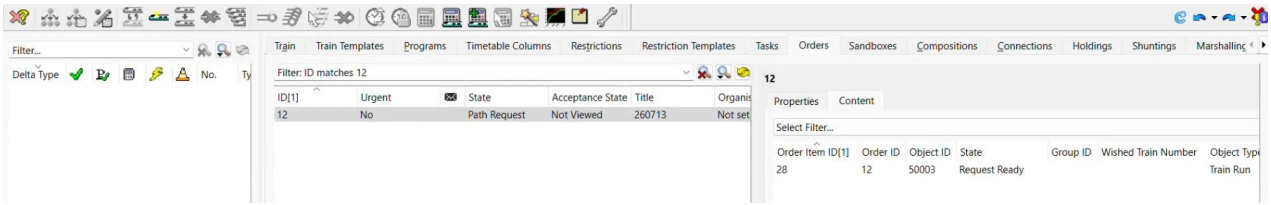



**Figure 9.5 – CMS receives a new Late Path Request**

After that a new message is sent with the information for an offer. CMS receives the message and creates an offer. The offer has all the information to create the train run, such as the ODT of the train, the first and last operating day and the departure and arrival stations as shown in Figure 9.6.

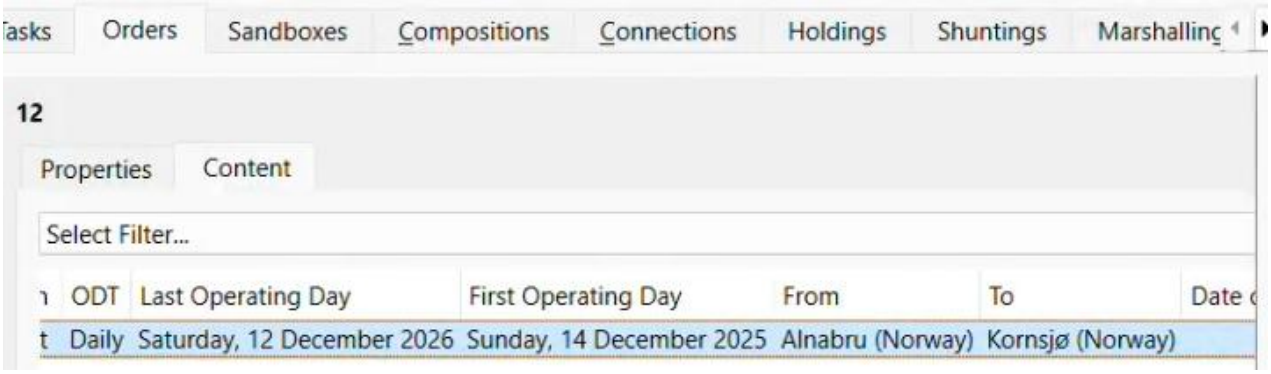



**Figure 9.6 – Offer created in the CMS with corresponding train run information**

After that, a new message is sent to the CMS system to create a new offer item associated with the offer and change the state to "In Progress". At this point, the train is created and visible in the CMS so that the capacity planner can update the train parameters accordingly to the remaining timetable plan as shown in Figure 9.7. Once the parameters are updated, the train run is calculated.

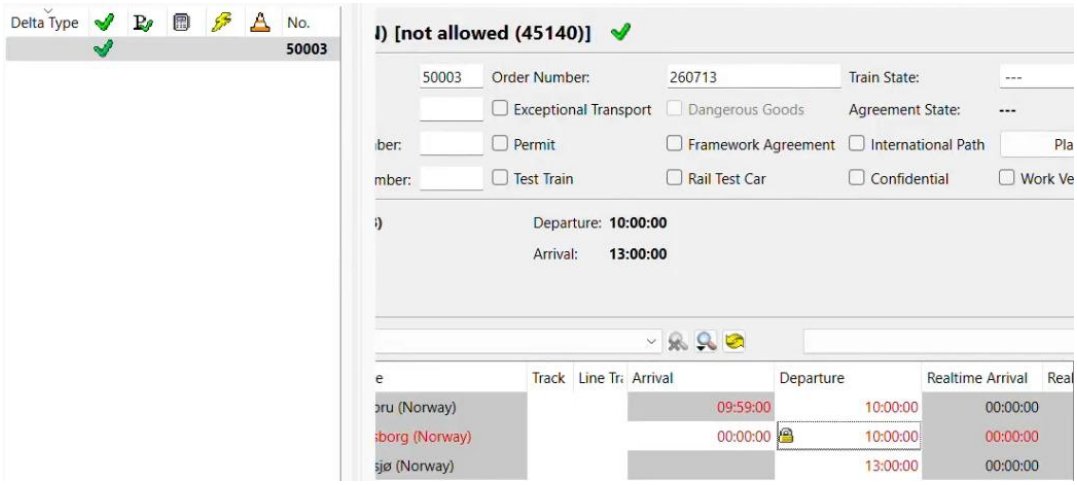



**Figure 9.7 – Train created in the CMS and ready to be scheduled**

The capacity planner uses the CMS to change the offer item to the new status “ready for sending update”. And after that the capacity planner can select the action of “send update” so that the CMS sends offer completion information to the PCS system as shown in Figure 9.8.

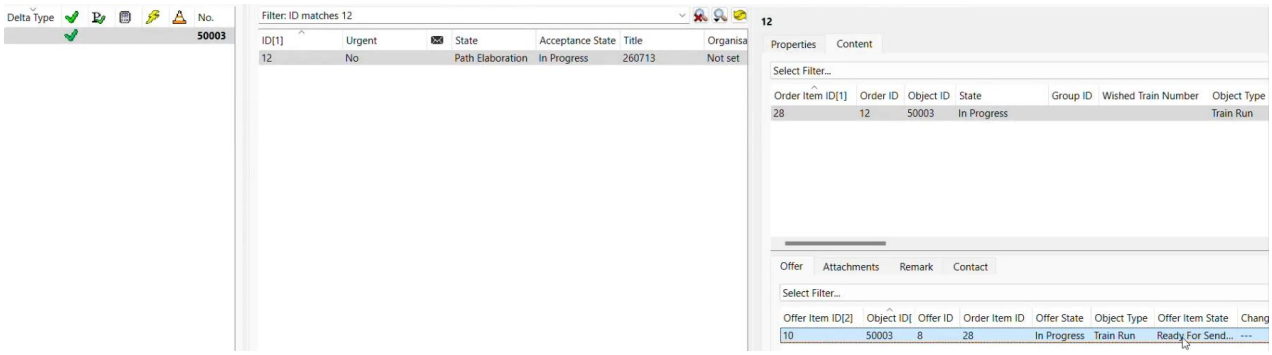



**Figure 9.8 – Scheduled train information sent to the PCS**

The PCS system will receive the updated information of the train run accordingly to the timetable created in the CMS.

During the validation event it was possible to show that the CMS supports bi-directional system-to-system integration with the RNE PCS for the exchange of international path requests and related capacity data, via both the PCS Integration Platform (web services) and the Telematics TSI CI. Resulting benefits are:

- The bi-directional, system-to-system integration means data flows automatically between the CMS and PCS in both directions.
- Customers don't need to build or maintain their own middleware or custom connectors to bridge the CMS and PCS.
- Customers using the legacy Telematics TSI CI don't need to immediately migrate to the newer PCS as the integration platform and the CMS supports both.
- Customers can be confident that as international capacity management standards and processes continue to evolve, the CMS evolves with them — ensuring a smooth transition without disruption to their operations or the need to change systems.

During validation event 3 we presented the exchange of information between TPS.plan and PCS.

Specifically, we demonstrated an incoming path request received into TPS.plan, and the resulting offer submitted from TPS.plan to PCS. Thus, our demonstration on the day focussed on showing the use case from the perspective of a user of the national CMS.

End-users participating in the event were satisfied with the extent to which the simulated interface between PCS and TPS.plan functioned, confirming that incoming and outgoing message flows along with the corresponding processes were correctly implemented in the CMS. The quantitative feedback for Demo 5.3 (PCS) is summarized in Table 9.1, providing an overview of participant perceptions regarding functionality usefulness, demonstration clarity, and effectiveness in addressing challenges.

**Table 9.1 – Demo 5.3 (PCS) Quantitative Questionnaire Results**

| Question\Participant | #1 | #2 | #3 | #4 |
|---|---|---|---|---|
| Overall, how useful do you find the functionalities demonstrated today for your work as a timetable planner/dispatcher? | (4) Very useful | (5) Extremely useful | (4) Very useful | (3) Moderately useful |
| How clear and easy to understand were the demonstration use cases presented today? | (5) Very clear | (5) Very clear | (4) Clear | (4) Clear |
| How well do you think the demonstrated processes address current challenges you face in managing railway capacity and planning? | (4) Very well | (4) Very well | (4) Very well | (3) Moderately well |

Verbal feedback during the session was that the users, who did not have prior knowledge of the role or functioning of PCS, were highly satisfied that regional initiatives were facilitating closer collaboration and visibility on an international level by leveraging the functionality of the independent national CMS combined with the availability of the regional platform and approach for standardised data exchange.

However, participants raised many questions during the demonstration, for example:

- How does it work when national IMs offer changes to the train path that are incompatible? For example, when the origin country proposes a delayed departure time, and the consequent delayed arrival time at the handover location is not suitable from the perspective of the receiving country
- How are the changes proposed by IMs made in the CMS relayed back to the RU?
- Do all national TMS systems (for example those offered by other service providers) capable of sending the amended train path offer to PCS?

The above questions were answered by the panel of experts present at the session, and the session concluded with participants satisfied in the answers. However, the questions highlighted an important consideration, that when performing demonstrations of such new and innovative regional initiatives, participants benefit from receiving more thorough background and contextual information prior to the start of the formal demonstration to ensure that all perspectives (not limited to the focus of the demonstration itself) is well covered.

The implementation of Demo 5.3 and its integration with RNE's PCS-CB have several significant real-world impacts:

- Enhanced Cross-Border Planning: The system significantly improves the efficiency and coordination of international train path requests, reducing manual effort and potential errors in cross-border operations.
- Improved Capacity Management: By enabling dynamic and timely exchange of capacity information and TCRs, the system allows for more effective utilization of rail infrastructure across national boundaries.
- Increased Interoperability: Adherence to Telematics TSI standards ensures better interoperability with other European rail systems, enabling a more harmonized and integrated European rail network.
- Faster Response to Operational Changes: The ability to process late and ad-hoc path requests, combined with TCR handling, allows railway undertakings to respond more flexibly to operational changes and disruptions.
- Streamlined Workflows: The adapted workflow states and state machine for Ordering Engine, Order Item, and Offer Item, streamline internal CMS processes, leading to greater operational efficiency for capacity planners.

Building upon the achievements of Demo 5.3, future work could explore several avenues to further enhance the integrated planning capabilities:

- Expansion of Use Cases: Investigating the integration of additional use cases or new scenarios to cover a broader spectrum of operational needs.
- Performance Optimization: Further optimising the performance of the Kafka messaging system and the CMS Application Servers to handle even higher volumes of requests and data.
- User Interface Enhancements: Continuously improving the CMS user interface based on ongoing user feedback to enhance usability and reduce training time.
- Broader Integration Landscape: Exploring integration with other relevant external systems beyond PCS-CB to create an even more comprehensive and interconnected planning ecosystem.

# 10. Demo 5.4 – Collaborative yard capacity planning

The Yard Coordination System (YCS) is an operational planning system for the tracks in the arrival/departure yard over the coming 24-hour period. All parties use YCS in their planning and thereby obtain a shared situational picture of conditions in the yard. This enables the parties to:

- improve the utilisation of yard resources;
- improve train planning for the Line Manager (LM) and planning of train-related needs for the Yard Manager (YM) and Terminal Manager (TeM);
- increase the degree of automation and thereby reduce manual workload; and
- improve the conditions for handling disruptions and ad hoc requirements outside the timetable.

Two freight operators are active at the Malmö freight yard: a yard operator and a terminal operator. Trafikverket regulates traffic within the arrival/departure yard and on the main line. At present, communication among the parties is inefficient, resulting in suboptimal use of resources and reactive responses to disruptions, which in turn create considerable stress.

Demonstration 5.4 focuses on four use cases (see next section) while also addressing automation support for the LM, work efficiency, and information visualisation. YCS is intended to be tightly integrated with Trafikverket's Digital Graf[1], and the two systems are designed to operate in parallel. Digital Graf is the master of planned train ETA/ETD and YCS integrates with Digital Graf to obtain planned train ETA/ETD. However, YCS is the master of track allocation of trains on the Malmö freight yard, arrival/departure yard. In the demonstration, recorded data from Digital Graf is used and provide the basis for three realistic scenarios and one test scenario used during the validation event. YCS is also part of Motional WP11/12 (which uses YCS together with Digital Graf integration) and TRANS4M-R; further information is provided in Deliverable D2.5 (see, FP1-MOTIONAL, 2024b) and D4.1, (see, FP1-MOTIONAL, 2024c).

## 10.1. Method and development Demo 5.4

The first major focus of YCS development are the four use cases:

- UC-FP1-WP3-10: YCS: Update the initial Arrival/Departure-yard plan and make it conflict free for the next few hours.
- UC-FP1-WP3-11: YCS: Updated planned arrival times.
- UC-FP1-WP3-12: YCS: Wagons for departuretrain not ready for departure on time.
- UC-FP1-WP3-13: YCS: New shunting need from YM.

In UC-FP1-WP3-10, the LM, YM, and TeM can all make changes to trains in order to resolve conflicts. The LM can move trains to new tracks and can also shorten or extend the planned dwell time of a train on a track. Through Digital Graf, the LM can additionally modify train ETA and ETD, which are then captured by YCS and displayed in the interface. The YM and TeM can modify their operational needs for trains. Such changes may themselves generate new conflicts; however, all conflicts are visible to all roles, and the LM can resolve them by adjusting dwell times and/or changing ETA/ETD values.

[1] Digital Graf is an operational planning system, where trains are planned for the short future of 24 hours.

In UC-FP1-WP3-11, updated ETAs for trains are handled. These are changed in Digital Graf, which generates a new message to YCS. YCS processes the message and updates the database and interface so that all parties can see the change. The update may generate conflicts, which are displayed in the graphical interface and must then be addressed by the parties.

UC-FP1-WP3-12 addresses situations in which the YM/TeM are unable to complete their work on a train before departure and therefore extend their requested time window in YCS beyond the train's dwell time, thereby creating a conflict. In such cases, the LM must be able to modify the ETD in Digital Graf. A new message is then sent to YCS, which processes the message and updates both the database and the graphical interface so that all parties can see the change.

In UC-FP1-WP3-13, the YM and TeM can enter shunting movements on tracks. These receive a dedicated visual marking in the interface and become visible to all parties in YCS.

WP5 does not address the integration with Digital Graf, which is done in WP12. Because of that, changes to ETA/ETD are made possible in YCS graphical interface for demonstration purpose of WP5. In reality changes to ETA/ETD should be done in Digital Graf.

YCS can display two types of conflicts, see Figure 10.1:

- two trains assigned to the same track with overlapping dwell times; and
- YM/TeM requested time window for a train that exceed the train's planned dwell time on the track.

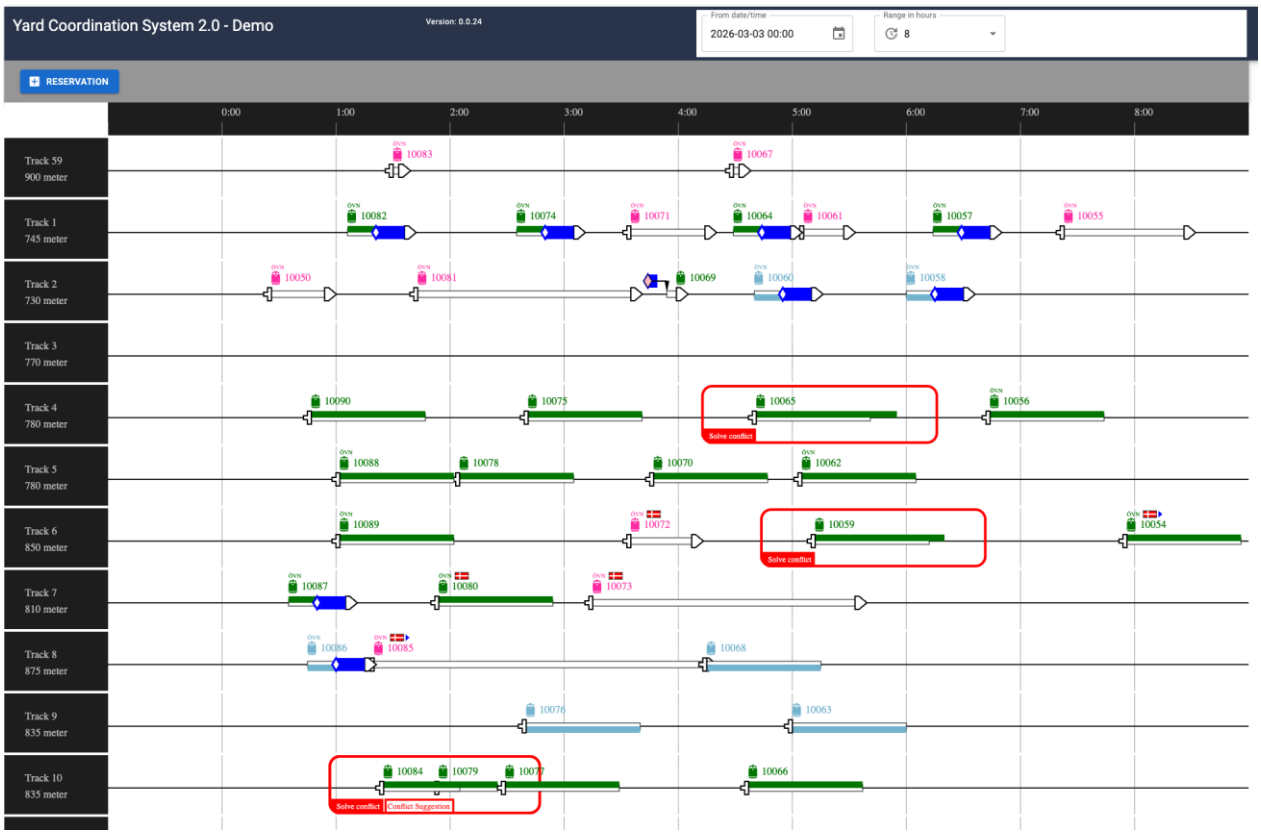



**Figure 10.1 – YCS showing the tracks view. Three conflicts are visible. Note, the train numbers in this view are synthetic. Real train number where, though, used in the Validation Event.**

We chose not to implement additional conflict types, as these implemented are expected to be the most frequent and the most important. YCS currently handles three types of objects:

- trains (received from Digital Graf);
- shunting movements (entered by the YM/TeM); and
- track maintenance activities (entered by the LM).

All of these objects can generate conflicts if they overlap in time. At present, YCS does not consistently handle situations in which more than two such objects overlap simultaneously.

The second major focus of YCS development is automation support for the LM. YCS implements:

- default planning of new trains received from Digital Graf;
- a `Solve Conflict` button, which is displayed only for the LM when a conflict exists; and
- a `Conflict Suggestion` button, which is displayed only for the LM when a conflict involves two trains with overlapping dwell times.
- early times of trains to Malmö freight yard, still in Denmark.

Default planning automatically assigns trains to tracks according to predefined rules. Trains arriving from or departing towards Östervärn station cannot be assigned to Tracks 9 and 10. Certain operational train numbers correspond to trains with mail delivery wagons and are assigned to Track 10 even if this may create a conflict. Trains passing through Malmö freight yard without any traffic exchange are assigned to Track 59. Departing trains are primarily assigned to Tracks 1, 2, and 4, whereas arriving trains are assigned to Tracks 5-10. Track 3 is intentionally kept free. Most trains are handled by the YM, although YCS can identify a subset of trains handled by the TeM.

The `Solve Conflict` button is shown whenever a conflict exists. If it is clicked when the conflict is caused by YM/TeM requested time window extending beyond the train's planned dwell time on the track, the dwell time is extended. If it is clicked when two trains have overlapping dwell times, one of the trains is moved to another track. In the latter case, YCS internally creates a ranked list of all possible outcomes resulting from moving either train. The algorithm selects the highest-ranked option, which represents the preferred solution.

The `Conflict Suggestion` button displays the internally generated ranked list of all possible outcomes resulting from moving either train, is displayed in a dialogue window. Each case includes a `Move Train` button which, when clicked, moves the specified train in accordance with that alternative.

Some trains are marked with a Danish flag. Some of these have an arrow besides the flag. These trains have actual arrival/departure time information, when still in Denmark. This functionality was a late implementation. The idea we want to test is the value of such information to LM.

## 10.2. Demonstration planning of Demo 5.4

During Autumn 2025, the **preparation phase** for the demonstration began. We established recurring meetings to enable continuous and frequent discussion and follow-up of the

preparations. We also created a GANTT chart that listed the activities and placed them on a timeline, see Figure 10.2. This plan formed the basis for the subsequent work. An additional colleague was involved to support the preparations and the continued work. The most important items in our planning included the following:

- Where should the demonstration be held? What equipment would be needed on site? Which premises should be booked?
- Who should participate in the demonstration? What equipment would users need to bring?
- How should the demonstration be documented?
- GDPR issues and permissions for photography and filming.
- A questionnaire for the participants.
- A system showing the current status of the tracks in the I/U yard, that is, which train is currently occupying which track.
- Which scenarios should be carried out during the demonstration?
- When should the users be trained?
- When should the demonstration be conducted? Would one day or two be required?

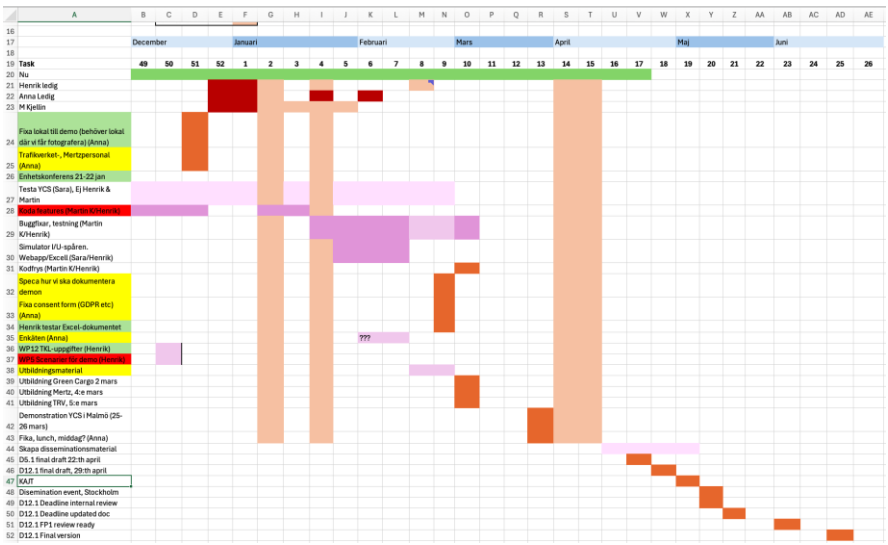



**Figure 10.2 – GANTT scheme of Demo 5.4**

After the Christmas break, the **implementation phase** began, with a focus on answering the preparation questions. We concluded that the demonstration should be held at Trafikverket's office in Malmö over two days, March 25-26, 2026. The venue provided the required equipment and sufficient space. We needed three smaller rooms in which the different roles could work and one larger room where all participants could meet for joint discussions.

The integration with Trafikverket's dataset of current arrival and departure times for trains in Denmark in Telematics TSI format was completed during the autumn of 2025. We elected to integrate YCS with this dataset, filtering for trains travelling from Denmark to Malmö freight yard. Trains originating from Denmark are indicated by an icon in the form of a Danish flag. In cases where timing data from Denmark is also available, this is denoted by an arrow displayed adjacent to the flag.

For the demonstration and the training sessions, we invited two representatives from Green Cargo, who had the role of YM in YCS; two representatives from Mertz, who had the role of TeM in YCS; and one representative from Trafikverket, a trained line manager with many years of professional experience, who took the role of LM in YCS. For the demonstration, we also invited additional representatives from Trafikverket who had been involved in YCS development over the years, as well as the leaders of WP5 and WP12, both of whom are from Trafikverket.

Training for the invited roles was conducted during Week 10 in early March, with each training session lasting two hours. Each role was assigned a dedicated training session and day, thereby giving all participants sufficient time to ask questions. At each session, we provided a thorough presentation of all YCS functions. The users were given login credentials and time to test the functions independently during the session. The credentials remained valid after the training, enabling the users to continue exploring YCS and thereby strengthen their knowledge and preparedness.

The questionnaire took shape during spring 2026 and ultimately consisted of 24 questions divided into nine sections.

The system showing the current status of the tracks in the I/U yard, called SpelLedare3 (game leader in eng.), was a very important part of the demonstration. Because YCS is a planning system, we also needed a system that could display the current status of the tracks. For this purpose, we were able to reuse a system called SpelLedare2, implemented in Excel. We further refined SpelLedare3, corrected bugs, and tested the system two weeks before the demonstration. The demonstration scenarios required a new role, simulation controller, responsible for determining and changing the exact current time. The simulation controller set the current time in the SpelLedare3 document and via a script in YCS, which shows current time as a line in the tracks/time view. In addition, the simulation controller performed the role of train driver by calling the LM upon train arrivals and departures. A staff member from RISE was appointed as simulation controller. The other RISE participants supported both the users and the simulation controller.

Three realistic scenarios were developed for the demonstration, along with one test scenario. The demonstration began with the test scenario, allowing the users and the simulation controller to test YCS and their respective roles. The three realistic scenarios were:

- a completely normal day;
- no trains from Denmark: a disruption near the Öresund Bridge prevented trains from Denmark from reaching Malmö freight yard between 02:00 and 16:00 on March 5, 2026. When the scenario began, traffic had only just started to resume, and six trains were delayed by as much as 14 hours; and
- a damaged switch just outside the freight yard, restricting how trains could move within the Arrival/Departure yard.

We selected and downloaded train data from Digital Graf covering February 25 to March 5, 2026. This could only be done after March 5. We also downloaded the Danish train data in Telematics TSI format (via our integration to Trafikverket's dataset). These data were uploaded to the demonstration instance of YCS. This YCS instance was not connected to Digital Graf and was used exclusively for the demonstration and its scenarios.

We also prepared a short presentation outlining the agenda for the two days, the relevant use cases, and the specific aspects on which we intended to focus during the demonstration.

During Autumn 2025, the final functionalities in YCS were implemented, and bugs were corrected throughout Autumn, Winter, and Spring. During spring 2026, the necessary scripts for the demonstration were also developed.



**Figure 10.3 – Validation event for Demo 5.4 at Trafikverket's office in Malmö**

In the **execution phase**, the validation event took place at Trafikverket's office in Malmö on the 25th of March. All RISE and Trafikverket participants arrived at 08:30 to complete the practical preparations. At 10:00, everyone gathered in the larger room, where we opened the demonstration with a slideshow and presentation, see Figure 10.3. At 10:45, all participants remained together to run the first scenario, the test scenario, until lunch. After lunch, the different users moved to separate rooms, supported by staff from RISE and Trafikverket, and ran the scenario "a completely normal day," which lasted 60 minutes. At 15:00, we ran the final scenario of the day, "no trains from Denmark," with all participants gathered again. This scenario lasted 45 minutes. Finally, all five users completed the questionnaire. On March 26, 2026, at 10:00, we ran the last scenario, "a damaged switch just outside the freight yard," until lunch. Each scenario was followed by a discussion of approximately 30 minutes.

In the **evaluation phase**, the results from the validation event were processed and analysed. The result was presented at the dissemination event "Cross-border planning" in Solna, Sweden, on the 13th of May 2026, and at the Swedish event "KAJT vårseminarium" on the 7th of May 2026.

## 10.3. TRL validation of Demo 5.4

YCS follows the Horizon 2020 (H2020) definition of Technology Readiness Level (TRL). YCS aims to satisfy H2020 TRL 6, which is defined as follows:

- Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

YCS has been developed over many years, during which Trafikverket, Green Cargo, and Mertz have reviewed the work and provided feedback at regular intervals, a few times per year. YCS uses train data from Trafikverket's Digital Graf and Telematics formatted train data from Trafikverket concerning trains operating in Denmark. Digital Graf is not yet in operational use, and we therefore rely on a test instance of Digital Graf containing data primarily from Trafikverket's C-DAS dataset. However, these data originate from Trafikverket's various TMS systems. The data are therefore sufficiently close to production data to satisfy the requirements of TRL 6. The scenarios were developed together with trained Trafikverket personnel who had worked as line managers for many years. All YCS users participating in the demonstration were representatives of the organisations responsible for planning train arrivals and departures or planning work on trains at Malmö freight yard. They all participated in the discussions during the demonstration and completed the questionnaire. This ensured that the feedback obtained was relevant. We therefore conclude that YCS satisfies TRL 6.

## 10.4. Evaluation and results in Demo 5.4

The results of the demonstration held in Malmö consist of the responses to the questionnaire completed by the participants and the discussions that followed each performed scenario. The questionnaire comprises 24 questions divided into 9 categories:

- First impressions
- Usability (UX and functionality)
- Follow-up: what would you change first if given the opportunity to prioritise?
- Utility and value
- Implementation and real-world application
- Data and reliability
- Collaboration and stakeholder perspectives
- Future outlook
- Concluding remarks

Five participants in the demonstration responded to the questions in the questionnaire.

Following an analysis of all questions and responses, it can be concluded that YCS constitutes an important and valuable tool, as it provides all parties with a shared understanding of the situation at the Arrival/Departure yard, thereby affording a stronger basis for decision-making. It facilitates shunting operations, the sorting of trains, and the planning of these activities, as well as disruption management. It enhances punctuality and collaboration at the freight yard and renders existing capacity more readily visible. A considerable degree of guesswork is eliminated. In high-pressure situations, the system makes it possible to ascertain what can feasibly be accomplished within a given timeframe. Shortages in track capacity can be identified well in advance of their occurrence. The system reduces the time during which trains remain involuntarily stationary and improves coordination and cooperation between the parties involved. One participant reported that the system was easy and quick to learn, whereas another maintained that a thorough familiarisation was required in order to understand it fully. The functionality is in place but requires further refinement in terms of user-friendliness.

The principal area identified for improvement in YCS, noted to varying degrees by numerous users,

is the user interface. Some participants considered the layout and symbols employed to be sufficiently adequate, while others found them confusing or less than intuitive. YCS should adopt the Swedish Transport Administration's established graphical profile for systems (the MTO perspective) and align more closely with Digital Graf in terms of visual design. If YCS is not straightforward to use and comprehend, there is a risk that it will not be adopted. One participant argued that the UX must be of the highest possible standard in order for the system to be used. Should it not be employed by all relevant parties, a substantial portion of its intended purpose will be lost. The Solve Conflict function was regarded as highly effective and useful. Users expressed a wish to reduce the number of clicks required to perform a given task. Desired features included the ability to grasp a train (with the mouse) and drag it to another track (drag-and-drop), to grasp the end of a track reservation and drag it with the mouse to the desired position, and to manipulate a slider on the screen—or scroll with the mouse wheel—in order to zoom the view and scroll along the time axis. Drag-and-drop of trains, mouse-based dragging, and zoom functionality were implemented in YCS 1.0 within the Freight2Rail project, and it was decided not to re-implement these features, as Freight2Rail had already addressed these questions, demonstrating that the functions are productive, user-friendly, and practical. Missing features raised by the participants included:

- The ability to communicate with counterparts via text was identified as a desired feature.
- The incorporation of traceability, so that capacity utilisation can be assessed still more efficiently in future follow-ups.
- YM and TeM should be able to enter additional information.

Some users considered that excessive emphasis was placed on trains originating from Denmark (which are displayed with an icon in the form of a Danish flag). Current arrival and departure times for trains still located in Denmark and bound for Malmö freight yard are valuable; however, the train dispatcher already has access to this information through existing systems. Consequently, this information should not be included in YCS in any future production implementation.

The significance of a requirement from YM/TeM and a reservation made by the LM is not clearly defined within YCS. These concepts should be more precisely defined, or supplemented with symbols, so that the LM can ascertain exactly when shunting has been scheduled for a given train. A further consideration is whether both YM/TeM and LM genuinely need to place markings on a train. Might it suffice for the LM to plan the stopover at a track and for YM/TeM to indicate only when their requirements extend beyond the duration of the stopover? One participant also questioned what a reservation (by the LM) actually entails in practice.

Participants were invited to identify the risks they associated with YCS. One such risk arises if participants do not, or cannot, achieve a shared understanding, which may give rise to conflicts. A further risk pertains to the possibility that the necessary settings cannot be configured within YCS. All users must be willing to use YCS in a truthful manner; that is to say, they must refrain from booking capacity as a precautionary measure.

Many participants considered that YCS supports and aligns with current working procedures. A prerequisite, however, is that YCS receives train data from Digital Graf, which must therefore also be an operational system in active use. A rollout of the system will require that as much information as possible is derived from integrated systems. Integration with Digital Graf is a

necessary condition, though integration with future shunting systems would likewise be advantageous—as would integration with systems providing current arrival and departure times, as well as train monitoring systems (along the route of a given train). One participant observed that integrating YCS with their own systems would require considerable effort, though it would not be impossible. Care should be taken to ensure that as much as possible occurs automatically, thereby enabling YCS to concentrate on functioning as a problem-solving tool. A rollout will also necessitate user training, together with the opportunity for users to trial the system through scenario-based exercises, as was the case at the Validation Event. YCS cannot be employed in safety-critical decision-making, as the system is not a safety system.

The Validation Event in Malmö proved to be both highly productive and a considerable success. All participants were deeply engaged throughout the event and were able to provide an adequate and professional evaluation of YCS. Their responses will inform the further development of YCS, with the aim of creating a system that delivers the greatest possible value to its users and exerts a positive influence on operations at the Malmö freight yard. The participants were unanimous in their view that YCS represents a tool that all stakeholders at the Malmö freight yard have long wished to see realised, and that it will be of considerable value to all parties involved once it enters operational use.

The work on YCS demonstrates that effective information exchange constitutes the foundation of efficient operations. YCS has made considerable progress towards deployment in operational use, which remains the overarching objective. A substantial degree of stress and reactive behaviour can be avoided if all stakeholders are provided with the same truthful representation of the situation at the freight yard. Under such conditions, stakeholders are able to plan their activities and take timely action, and collaboration proceeds more smoothly and effectively.

Through the participants' evaluation and discussions, a solid foundation has been established for future work on YCS. In the second wave of MOTIONAL, the intention is to advance the development of YCS in order to attain TRL 7, together with a still more extensive integration with Digital Graf and other systems. At present, YCS is developed exclusively for the Malmö freight yard, encompassing the Arrival/Departure yard. The underlying concepts are applicable to any freight yard; however, Malmö was selected deliberately, given that the situation there is particularly challenging. Malmö freight yard also constitutes a cross-border station, as trains operate to and from Denmark, which further complicates the planning process. YCS could additionally display a greater level of detail, such as locomotives, or a more extensive section of the freight yard. There is also scope for increased automation. For instance, a background process could be tasked with relocating trains (approximately one to five hours prior to arrival or departure) in order to optimise capacity and accommodate new information as it becomes available to the system. The user interface, as noted by numerous participants, likewise offers potential for improvement. These reflections represent merely a selection of possible directions. The continued development of YCS will be pursued in still closer collaboration with all stakeholders involved, as well as with the development team responsible for Digital Graf.

# 11. Demo 5.5 – Improved capacity allocation and new processes

For the Demo 5.5, HACON focuses on the design and development of a demonstrations supporting the WP 5 objectives for:

- TE 1: European cross-border scheduling with international train path planning
- TE 2: Improved capacity allocation using rolling planning and TTR

The development was based on the results of the activities in Subtask 5.2.2 (achieving TRL 6) to show improved national CMS enabled for new European-wide capacity allocation and consideration of new processes in capacity planning, especially following the process descriptions provided through the TTR initiative of the RNE and the current regulation proposal for the future European capacity management process.

The development for Demo 5.5 covers the following WP 3 use case:

- Planning and allocation of capacity for different planning horizons (UC-FP1-WP3-4)

In accordance with MOTIONAL D4.1, the scope of functionality addressed by the demonstrations is reflected by the following topics:

1. Create, display, change and delete a train path envelope (Slot).
2. Create, display, change and delete a TCR.
3. Create, display, change and delete a Capacity Band.
4. Manage Slots as part of a Capacity Band.
5. Multi-annual capacity model objects.
6. Multi-annual capacity requests.
7. Upload of Capacity Model data to ECMT (RNE).
8. Management of planned changes of the infrastructure.
9. Evolving infrastructure linked to the Capacity Model.
10. CMS report on TTR planning status

In the Demo 5.5, the capacity management system (CMS) generates a file compatible for uploading of Capacity Model data to the ECMT tool currently developed by RNE to improve the alignment of European capacity planning results. The messaging required for this purpose has been recently specified in the System Pillar Task 3 providing a first version of the specification in September 2025. For the Capacity Model data types Path and TCR, the related (draft) TSI specifications have been assumed and shown already in Demo 5.3. Thus, our TRL6 Demo 5.5 does not yet show a solution fully integrated with the ECMT as required in no. 7 above. The tests for no. 2 above (Create, display, change and delete a TCR) have been successfully performed already under Demo 5.3 so the TRL6 testing for Demo 5.5 was centered around the 'new' Capacity Model objects, i.e., Train Path Envelopes (Slots) and Capacity Bands.

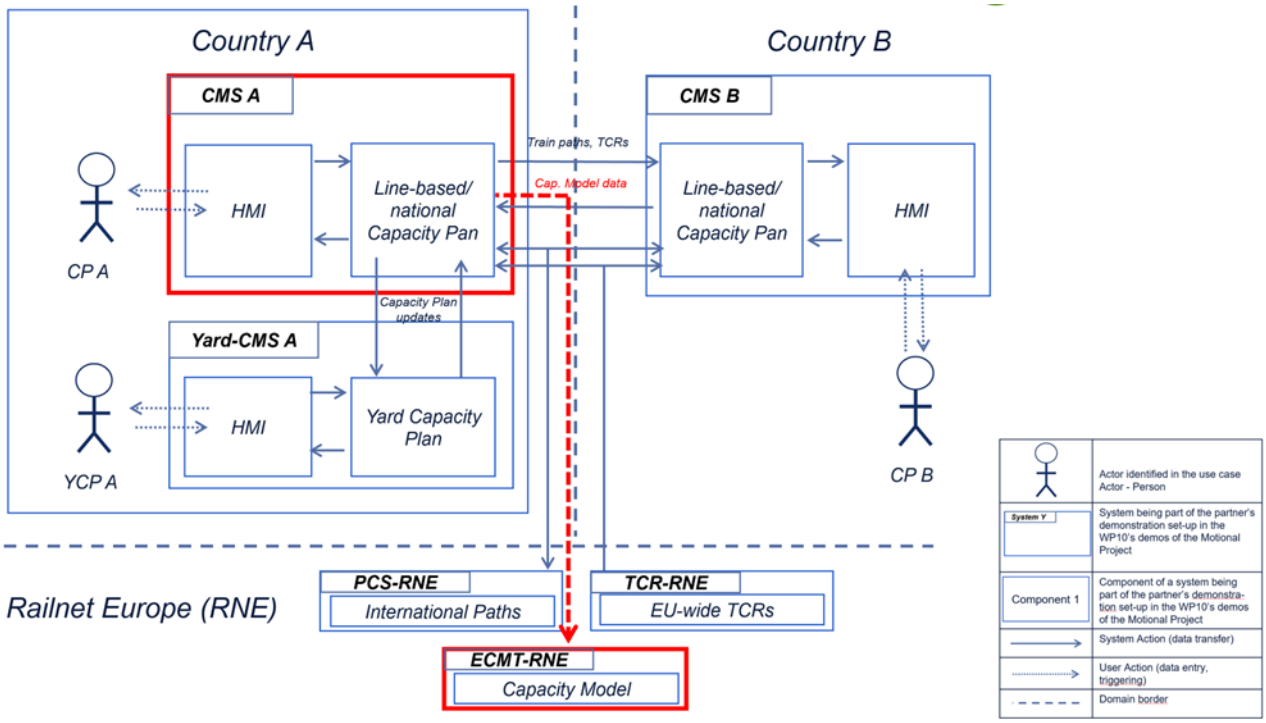



**Figure 11.1 – General system concept of Demo 5.5**

## 11.1. Method and development for Demo 5.5

The development of Demo 5.5 was based on the results of activities in Subtask 5.2.1, which aimed at achieving TRL 6.

Rail infrastructure capacity across Europe is a limited resource and, because of that, heavily congested. As demand grows and cross-border operations become increasingly common, multiple operators compete for access to the same tracks, often spanning national boundaries and multiple planning horizons. Efficient allocation of this finite capacity is important for the efficient functioning of the European rail network.

The core development for Demo 5.5 was centered on enhancing the internal mechanisms of the CMS for capacity allocation and the introduction of new, more efficient planning processes. These processes are specifically designed to improve how capacity is managed, thereby enabling more efficient rail network management. A key focus of this development is to support enhanced cross-border planning, which is crucial for the functioning of international rail traffic. Furthermore, the new processes are tailored to support short-term planning activities and bring significant process improvements among all involved actors in the rail planning ecosystem. This foundational work directly contributes to a more harmonized and effective planning process across different national systems.

The scope of the functionality addressed by the demonstrations follows the Use Cases and Requirements as described in 'Deliverable 4.1 Integration of Planning Systems'. As such, the main component involved is the CMS itself, with potential interactions with external systems for data input or output.

The implementation comprised the development and integration of:

- Train Path Envelopes or Slots: Allowing the CMS Operator to define new train path envelopes and temporary capacity restrictions, specifying their parameters such as time, duration, location, and impact on capacity. This includes defining the characteristics of a slot, which represents a pre-defined capacity offer.
- Capacity Bands: Allowing the CMS Operator to define new Capacity Bands, which are aggregations of capacity over longer periods, often used for long-term agreements with railway undertakings. These bands, along with TCRs (as managed in UC1), form the basic constituents of the Capacity Model.
- Capacity allocation for different planning horizons: The CMS was enhanced to allow the Operator to create, change, and delete multi-annual train paths. This supports a continuous, multi-year planning cycle.
- Seamless Transition to Annual Allocation: A key feature developed was the ability to initialise capacity objects for the upcoming timetable period from the multi-annual plan. This ensures that as a new annual timetable period approaches, the capacity objects (e.g., slots) are adapted or converted into specific train paths for the corresponding long-term path (LTP) allocation process, all without negatively impacting the overarching multi-annual plan. This ensures continuity and consistency across planning horizons.
- ECMT export: A feature to allow the CMS Operator to initiate the transfer of Train paths and TCRs to the ECMT.

The integration of these functionalities within the CMS is critical for flexible and responsive capacity management, particularly in a cross-border context where regional standards for train paths and TCRs are paramount.

The test scenarios were designed to reflect real-world planning challenges. This included the handling of complex capacity requests and the management of various planning constraints, aiming to demonstrate the benefits of improved capacity allocation and new processes in diverse rail traffic situations.

## 11.2. Demonstration planning of Demo 5.5

During the **preparation phase**, the necessary infrastructure data model was prepared. For this demonstration, a specific section of the Norwegian rail network was selected to showcase the improved capacity allocation.

For the conducted tests, various capacity request scenarios were designed, including normal requests, complex conflict situations, and scenarios requiring dynamic re-allocation.

For the **implementation phase**, it was considered that the CMS supports the integration of new algorithms and processes for enhanced capacity planning allocation. This involved developing and integrating the new functionalities directly into the CMS. Benefits are:

- Optimized Resource Utilization: The new algorithms lead to more efficient use of available rail infrastructure, reducing bottlenecks and increasing overall network capacity.

- Reduced Planning Time: Streamlined workflows reduce the time required for planners to assign paths and resolve conflicts.
- Adaptability: The CMS becomes more adaptable to changing user demands and regulatory requirements through its flexible architecture for integrating new processes.

In the **execution phase**, the demonstrator was executed according to the planned test scenarios. The results, such as optimized path assignments, reduced conflicts, and faster planning cycles, were recorded and compiled into different videos used as evidence for the validation event.

Planners were able to testify the different situations through the different videos together with a brief explanation given in a presentation. The interaction was mainly done using the CMS via the client user interface, utilising the new allocation tools and processes.

## 11.3. TRL validation of Demo 5.5

For carrying out the tests, the test strategy is to focus on the requirements as well as on usability and the need of system requirements and functionality. These test procedures include:

- **Functional tests:** these are defined based on the specific Test Cases.
- **Feature testing**: In this phase, any modification being done (because of the functional tests) by the developers is tested to ensure the functionality is implemented correctly.

The overall test procedure is to implement in the defined Test Frameworks to:

- Verify, given an input, e.g., if a JSON message is correctly created with the correct format and expected information to be processed via the interfaces.
- Verify the result, e.g., messages received, GUI snapshots indicating sending or receipt of messages, showing changes in application GUI.

The objectives of the testing activities are:

- verifying that the requirements are met;
- evaluate results of other activities such as requirements, Use Cases, design and code (where applicable);
- find and prevent defects; and
- report the defects.

The verification of the defined use cases in the deliverable “Deliverable D4.1 Integration of Planning Systems” was done during the validation event that was held in Siemens Mobility Portuguese facilities in Aveiro, Portugal. The event took place on the 18$^{th}$ of March 2026. For the proposes of such validation, three end-users were present in the room with a background mostly of time tabling, namely in the Portuguese railway infrastructure, for the national infrastructure manager (see, Figure 11.2).

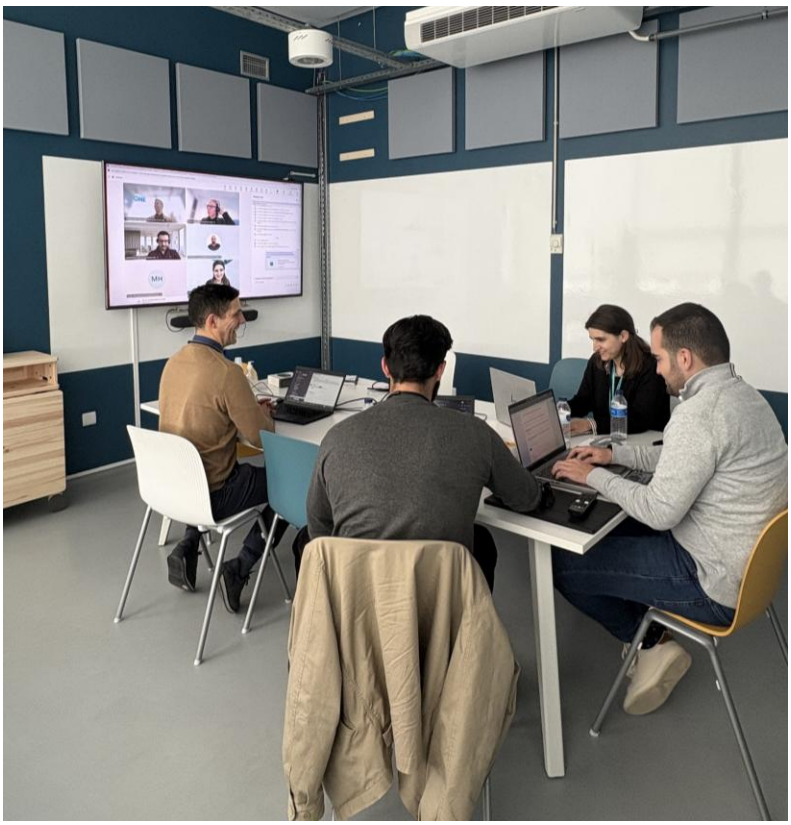


**Figure 11.2 – Validation event meeting at Siemens Mobility in Aveiro, Portugal**

Besides them, other system engineers and project collaborators have also participated remotely in the event. The end-users had no previous experience in using our CMS tool and were given an overview to the tool, before the presentation of the demonstration use-cases. Before the validation event, a document was also provided with training information on the tool and on the use cases.

As a closing activity of the validation event, quantitative and qualitative feedback was collected using a questionnaire. The questionnaire was like the one already presented in Demo 5.3 chapter of this document. The questionnaire was answered by the end-users present at the event.

## 11.4. Evaluation and results in Demo 5.5

The test cases results served as a base for the validation event of Demonstration 5.5 where it was possible to highlight how our developed solutions contribute to improved capacity allocation and the integration of new planning processes. Each screen provides a glimpse into the functionalities designed to support European cross-border scheduling, rolling planning, and the principles of the TTR (Timetable Redesign) initiative, specifically addressing the planning and allocation of capacity for different planning horizons.

The screen in Figure 11.3 demonstrates the core functionality for the CMS Operator to manage fundamental capacity elements: train path envelopes (slots) and capacity bands. Here, it's possible to see how the system allows for the creation, modification, and deletion of these critical components. The track section selected is between Narvik station (Norway) and Bjørnfjell station (Norway).

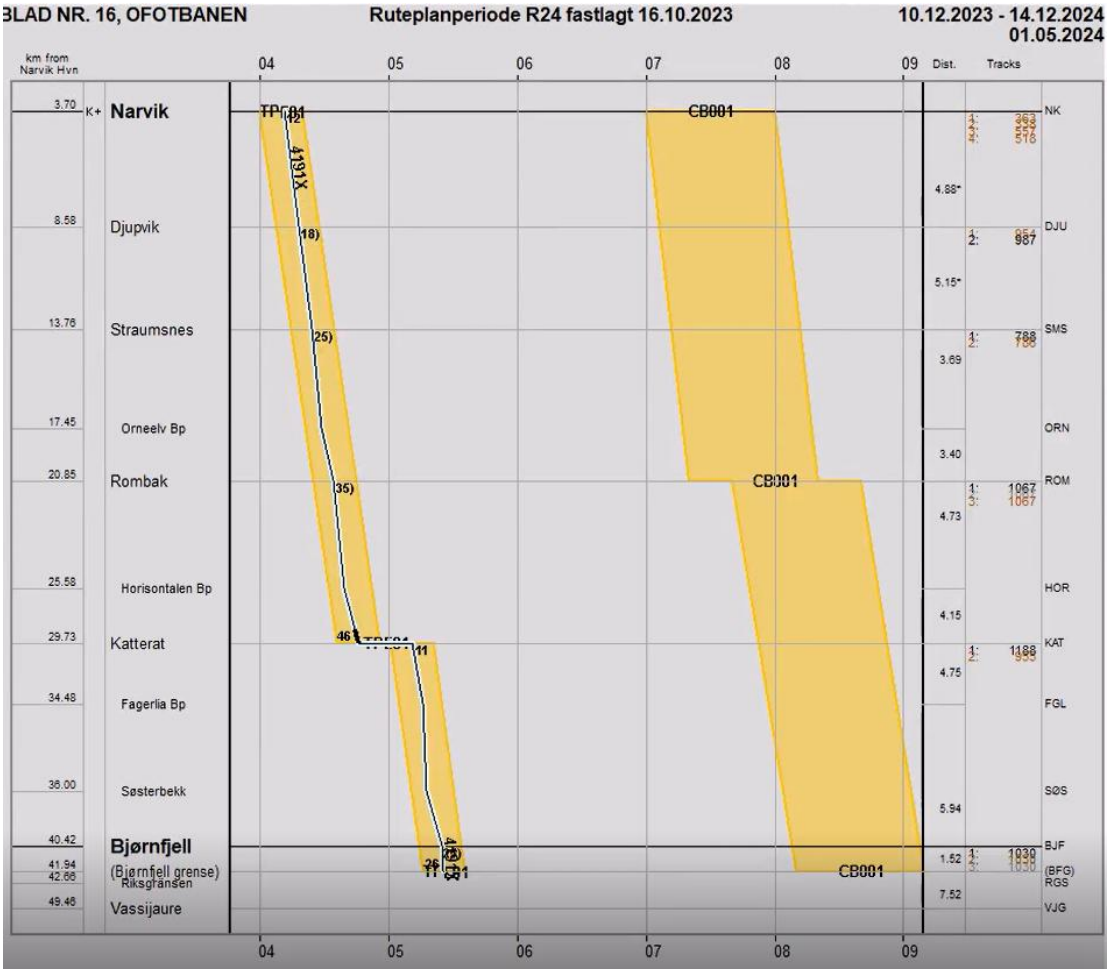



**Figure 11.3 – Train path envelope and capacity band as part of the planning process**

With the Train path envelopes, it was possible to showcase the system's ability to handle dynamic changes to railway capacity at a granular level, ensuring flexibility and responsiveness in planning.

Capacity bands are essential for the Capacity Model, supporting long-term capacity agreements and partitioning. This capability is essential for defining the basic building blocks of railway capacity, enabling precise control over when and where trains can operate, and how operational limitations are applied within the network. This direct manipulation of slots and capacity bands forms the foundation for effective capacity planning.

In a different test it was possible to demonstrate how the CMS handles a request for a multi-annual capacity plan. Specifically, the request considers a long-term capacity planning of 36 months (example 2023-2026) while the CMS system uses as a baseline an annual time period (example 2026) as shown in Figure 11.4. Based on this approach, if a multi-annual train is opened in a shorter project period, the CMS tool makes the train read-only because the train validity exceeds the project planning period.

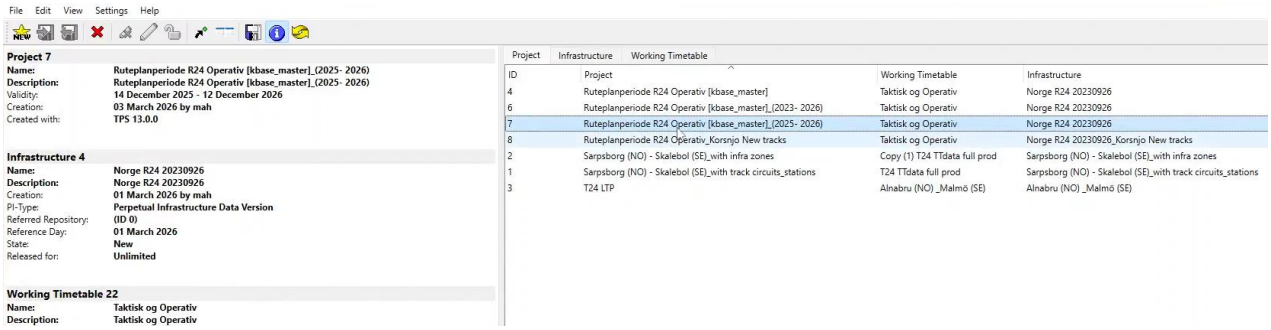



**Figure 11.4 – One year planning period**

The tested solution creates a copy of the multi-annual train in the sandbox of the annual project and then applies it to the working timetable of that project. This way the same working table can be used in multiple projects.

In Figure 11.5, the export of the capacity plan is exported accordingly to the ECMT format as defined by RNE.

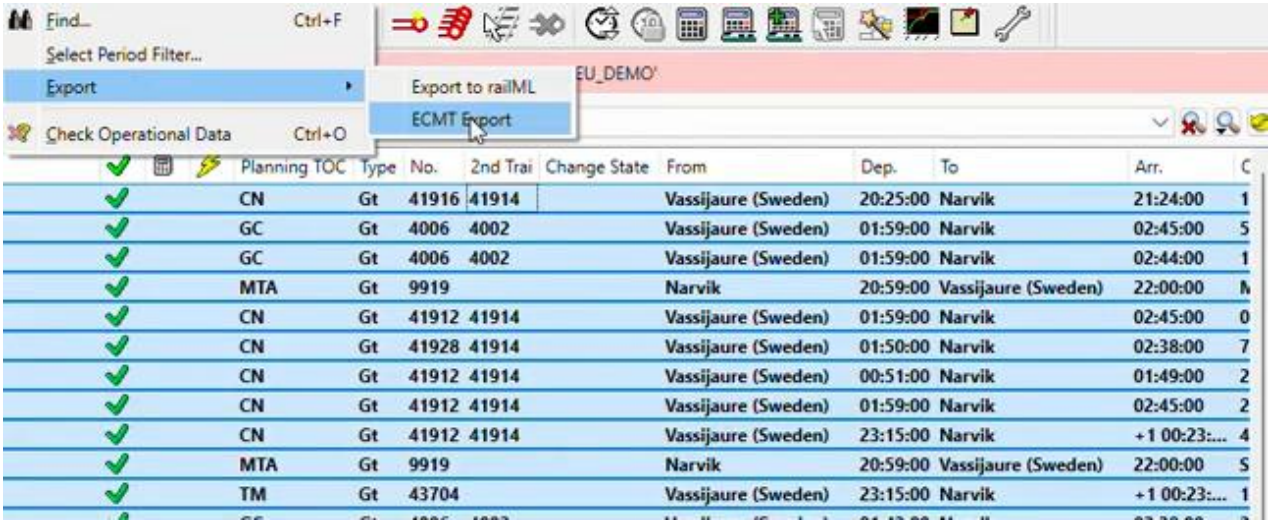



**Figure 11.5 – Starting a new ECMT export for international trains**

The Capacity Manager is able to initiate the export of time tabling information using ECMT format, in this case, using a set of trains between Vassijaure station (Sweden) and Narvik (Norway). With this use case it was possible to demonstrate the system's compliance with the TTR (Timetable Redesign) process by allowing the CMS Operator to initiate transfers of the Capacity Model, based on filter settings, ensuring seamless data exchange and coordination with external European systems.

The use case 5 "Managing Infrastructure Data Baselines and Capacity Plan Adaptations." effectively addresses the challenge of integrating future infrastructure changes into current timetable planning. The core problem addressed by this use case is how to incorporate future infrastructure changes (like new tracks, stations, or entire lines) into timetable planning before they become operational, without delaying the planning process. The CMS implements a pragmatic solution that differentiates between minor and major infrastructure changes.

For the minor infrastructure changes (e.g., adding a track at a station), the TMS extends the existing infrastructure model by directly incorporating the new element. Critically, this new element is assigned a future validity date. The system then enforces a validation rule: if a planned train path attempts to use this new infrastructure before its specified validity date, the TMS will flag it as an error, preventing invalid timetables. Once the validity date is reached, trains can use the new infrastructure without issue. This allows for seamless integration of smaller updates.

For major infrastructure changes (e.g., a completely new railway line), instead of modifying the existing model, the TMS creates an entirely separate infrastructure version or baseline. This new version reflects the significant future changes. A dedicated new project is then established within the TMS, specifically linked to this new infrastructure version. This project can also incorporate the same working timetable as the old infrastructure, allowing planners to adapt train paths to the new network layout. This approach provides a clear, isolated environment for planning against a substantially different future infrastructure, ensuring accuracy and preventing conflicts with current operations.

This flexible approach enables infrastructure managers to proactively plan for both incremental and transformative changes, optimising capacity and service delivery for evolving railway networks.

To evaluate the demonstrated solution during the validation event, a questionnaire was provided to the end users. The end users were able to answer all questions anonymously. The questionnaire included both closed questions and open-ended questions. The results are presented in Table 11.1. The overall answers show general positive feedback of the presented solution.

**Table 11.1 – Quantitative questionnaire results for Demo 5.5**

| Question\Participant | #1 | #2 | #3 |
|---|---|---|---|
| Overall, how useful do you find the functionalities demonstrated today for your work as a timetable planner/dispatcher? | (4) Very useful | (5) Extremely useful | (5) Extremely useful |
| How clear and easy to understand were the demonstration use cases presented today? | (4) Clear | (4) Clear | (4) Clear |
| How well do you think the demonstrated processes address current challenges you face in managing railway capacity and planning? | (3) Moderately well | (5) Extremely well | (4) Very well |

Additionally, the feedback was collected from four open text questions with the result presented in the following sections.

**Most Valuable Aspects/Features**
Flexibility and Visualization:

- Participant 1 highlighted "GTT" and the "Real time demo."
- Participant 2 valued the software's flexibility, specifically its ability to allow "generic definition of restrictions and operational scenarios."
- Participant 3 found the "geographical view and the 'occupation' track circuit layout" to be the most valuable.

**Areas for Improvement/Further Development**
Graphical Clarity and Introduction:

- Participant 1 suggested improvements in the "Real time demo."
- Participant 2 pointed out that "Some graphical indications could be more clear," specifically mentioning warning/error indications and similar colors in the geographical view.
- Participant 3 felt that the system appeared "very 'busy'" and would benefit from "some introduction to the main windows, menus and options/buttons."

**Integration with Existing Workflows and Tools (Potential Challenges/Benefits)**
Promising but Learning Curve:

- Participant 1 sees it helping to "integrate that in Porto's Operational Control Centre managed by Siemens Mobility."
- Participant 2 views it as an "improvement," but acknowledges a potential "learning curve for any new user."
- Participant 3 finds it "very promising" as long as the output timetable has all the necessary parameters for the existing ATS, and believes it "looks simple enough to use and to train new users."

Demo 5.5 significantly enhances railway capacity management by integrating various planning functionalities, leading to tangible benefits:

- Optimized Capacity Allocation: The ability to define and manage train path envelopes (slots) and Capacity Bands provides precise control over network capacity, reducing congestion and improving operational flow.
- Strategic Long-Term Planning: Multi-annual Capacity Bands and rolling planning capabilities enable IMs to plan years in advance, offering stability for Railway Undertakings (RUs) and supporting better investment decisions without impacting ongoing plans.
- Foundation for Future Integration: The work on uploading Capacity Model data to the ECMT (RNE) lays the groundwork for a more coordinated European capacity management system, even as the full integration is a future step. This forward-looking approach ensures long-term benefits for the entire European rail system.
- Proactive Infrastructure Integration: Managing distinct infrastructure data baselines with specific validity periods allows IMs to plan timetables for future network configurations (both minor and major changes) well before physical completion, preventing last-minute disruptions and optimising new infrastructure utilization.

Building on Demo 5.5's achievements, future enhancements could include:

- Automated Conflict Resolution: Developing algorithms to automatically detect and resolve conflicts across multi-annual plans, short-term plans, and infrastructure changes.
- Real-Time Data Integration: Deeper connection with live operational data for dynamic adjustments and immediate feedback on planning feasibility.
- Interactive Scenario Planning: User-friendly tools for "what-if" analysis of different infrastructure developments, demand forecasts, and operational strategies.
- Blockchain for Capacity Agreements: Exploring DLT for secure, transparent, and immutable management of multi-annual capacity commitments and RNE data exchange.
- Advanced Reporting Visualizations: Implementing interactive dashboards for deeper insights into planning volumes, trends, and KPIs.

# 12. Demo 5.6 – Integration of traffic management system with network capacity planning

For the Demo 5.6, HACON focuses on the design and development of demonstrations supporting the WP 5 objectives for:

- TE 2: Improved capacity allocation using rolling planning and TTR
- TE 6: Integration of TMS with a) yard capacity planning and b) station capacity planning

The development was based on the results of the activities in Task 5.2.3 (achieving TRL 6) focused on showing the integration of TMS with CMS to facilitate the implementation of a feedback link providing operational information from TMS to the CMS. Please note that the activity is a complementary activity to Demo 14.3 provided by WP 14.

The development for Demo 5.6 covers the following WP 3 use cases:

- Data exchange between traffic management system (TMS) and local or national capacity management/planning system (CMS) (UC-FP1-WP3-5).

In accordance with MOTIONAL D4.1, the scope of functionality addressed by the demonstrations is reflected by the following topics:

1. CMS Capacity Plan sent to TMS,
2. New or changed local plan of yard-based CMS sent to TMS,
3. New or changed operational TCR in TMS sent to national CMS,
4. New or changed operational TCR in TMS sent to local, yard-based CMS.

In the Demo 5.6, the national capacity management system (CMS) as well as the yard- or depot-based 'local' CMS provides the 'agreed plan' derived from the national or local capacity plan for the next 24 hours to the TMS. During the development phase and in the light of Use Case UC-FP1-WP3-6, it was decided to synchronise the local capacity plan updates with the national capacity plan managed by the CMS before sending the enhanced and updated capacity plan to the TMS using the system approach shown in Figure 12.1. Otherwise, the consistency of plan information delivered to the TMS could not be guaranteed. This is possible since the capacity plan database schema used for both, the local and the national CMS, is the same.

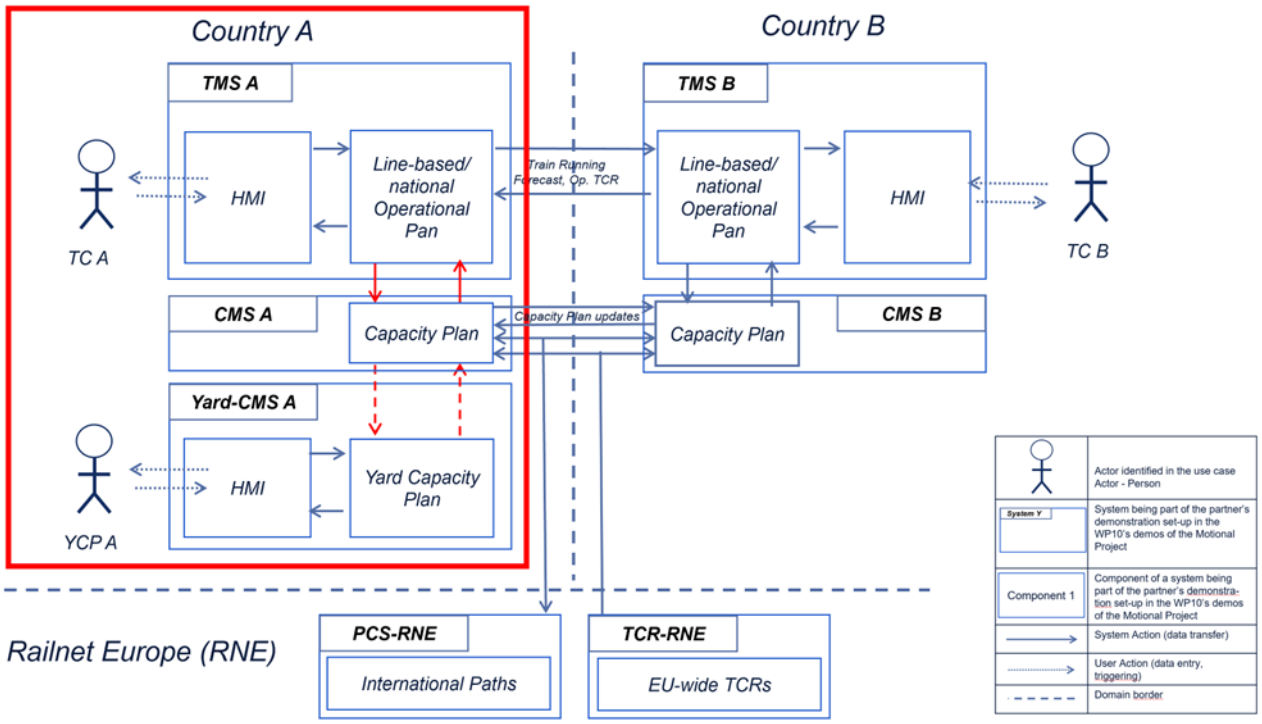



**Figure 12.1 – Overview of the system architecture for Demo 5.6**

## 12.1. Method and development for Demo 5.6

The development of Demo 5.6 was based on the results of activities in Subtask 5.2.3, which aimed at achieving TRL 6. This demonstration focuses on a critical aspect of modern railway operations: the seamless integration of Traffic Management Systems (TMS) with Network Capacity Planning systems (CMS). This integration is vital for establishing a feedback loop that provides operational information from the TMS to the CMS, thereby allowing the CMS to make more informed decisions and improve capacity planning.

Traditionally, traffic management and capacity planning have often operated in silos. This means that the feedback regarding discrepancies between planned timetables and real-time operational realities is not documented and provided to planners during the planning process. Demo 5.6 addresses this challenge by developing and demonstrating mechanisms for efficient data exchange, allowing the CMS to be informed by actual traffic conditions and operational changes. This foundational work directly contributes to more dynamic and adaptive rail network management, enabling appropriate adjustments to capacity plans based on accurate and relevant feedback.

The scope of the functionality addressed by the demonstrations follows the Use Cases and Requirements as described in 'Deliverable 4.1 Integration of Planning Systems'. As such, the main components involved are the CMS and the TMS, with a specific focus on the interfaces and data exchange protocols between them.

The implementation comprised the development and integration of:

- Bidirectional Data Exchange Interfaces: Establishing robust interfaces for the exchange of critical planning and operational data between the CMS and TMS.
- Operational Feedback Mechanisms: Implementing processes to feed operational data and changes from the TMS back into the CMS to better inform future planning.
- Enhanced Planning Adaptability: Enabling the CMS and TMS to react effectively to unforeseen disruptions or changes in traffic flow, leading to more resilient and realistic capacity plans and traffic management.

For the different use cases, the parameters were adjusted accordingly. For instance, when the TMS detects an operational change, such as an unplanned restriction, this information is communicated to the CMS. The CMS then processes this feedback, allowing the capacity planner to make necessary adjustments to planned train paths.

The test scenarios were designed to reflect real-world operational challenges, such as unexpected delays, infrastructure failures, or sudden changes in traffic demand. These scenarios aimed to demonstrate how the integrated system can effectively manage and respond to such events, highlighting the benefits of a continuous feedback loop between traffic management and capacity planning.

Specifically, the development encompassed the following key aspects of data exchange:

**CMS Capacity Plan Sent to TMS:**

The CMS is enabled to transmit its current capacity plan, including planned train paths, resource links and temporary capacity restrictions (TCR) to the TMS. This ensures that the TMS operates with the most up-to-date planning information, forming the basis for real-time traffic management. This transfer can be triggered by updates in the CMS or on a scheduled basis.

**New or Changed Local Plan of Yard-Based CMS Sent to TMS:**

In scenarios involving yard or station-level capacity management systems (local CMS), the integration allows for the transmission of new or modified local plans from these systems to the central TMS. This ensures that the TMS has a comprehensive view of planned capacity across the entire network, including short-terms changes to the plan made within yards and stations.

**New or Changed Operational TCR in TMS Sent to National CMS:**

A critical feedback mechanism developed is the ability of the TMS to communicate new or changed operational Temporary Capacity Restrictions (TCRs) to the national CMS. These operational TCRs might arise from unforeseen events like infrastructure failures, emergency works, or significant operational disruptions. By feeding this information back to the CMS, planners can rapidly assess the impact on the overall capacity plan and initiate necessary adjustments. This ensures that capacity planning remains realistic and responsive to operational constraints.

**New or Changed Operational TCR in TMS Sent to Local, Yard-Based CMS:**

The TMS is capable of sending new or changed operational TCRs directly to local, yard-based CMS systems. This ensures that local planners are immediately aware of any operational restrictions that might affect their specific area of responsibility, allowing them to adjust local plans accordingly.

The successful implementation of this use case significantly enhances the overall efficiency and resilience of the railway network. By integrating operational insights from the TMS into the planning processes of the CMS, railway infrastructure managers can achieve a more harmonised and adaptive approach to capacity management, leading to improved punctuality, reduced disruptions, and better utilization of infrastructure.

## 12.2. Demonstration planning of Demo 5.6

This chapter details the planning and execution strategy for Demo 5.6, outlining the objectives, methodologies, and evaluation criteria through four phases: Preparation, Implementation, Execution, and Evaluation. Demo 5.6 focuses on the critical synchronization and information exchange between national and local Capacity Management Systems (CMS) and the Traffic Management System (TMS), highlighting the synchronization of operational data.

The successful execution of Demo 5.6 focuses on the interoperability and data exchange between the National Capacity Management System (CMS), the Local Yard-Based Capacity Management System (CMS), and the Traffic Management System (TMS). The National CMS, responsible for overall rail capacity planning, demonstrates its ability to transmit capacity plans, including train paths and TCRs, to the TMS, showcasing its role in sending capacity plans to the operational system. The Local Yard-Based CMS highlights its capability to feed changes and updates to the plan, such as changed track allocations, and new shunting activities, to the TMS. The TMS, acting as the central traffic management system, receives and processes information from the CMS, translating planning data into operational plans and maintaining operational TCRs that are then reflected back into the planning systems. Key functionalities highlighted include timetable synchronization, real-time updates to the plan from yard systems, bidirectional TCR flow, and the maintenance of data consistency across all integrated systems regarding train path data and, TCRs.

For the **preparation phase** the infrastructure data model prepared for other demonstrations was reused for Demo 5.6. The timetable used to synchronise between the CMS and the TMS systems was based on national trains planned for Norway. For purposes of demonstrating the creation of restrictions, Alnabru station was used.

The **implementation phase** focuses on the technical setup and initial tests to ensure all systems are ready for use. This involves the deployment of configured versions of the national CMS, local yard-based CMS, and TMS in the dedicated testing environment. In this case, the scenarios were set up using infrastructure and timetable information from Norway.

End-to-end interface testing was conducted to confirm data exchange mechanisms are functioning correctly, including verification of message formats and data integrity during transmission via the interface. Several dry runs of all defined scenarios are performed to confirm the scenarios and refine the sequence of steps comprising the demonstration. Data validation confirmed the

accuracy and consistency of initial data loaded into each system across the interfaced systems.

The **execution phase** involved the live demonstration of predefined scenarios, with careful observation and data recording. Each scenario was executed according to the detailed test cases. This includes initiating changes in the national CMS (e.g., updated train path, new TCR) and observing their timely and accurate reflection in the TMS. Similarly, various operational changes were introduced in the local yard-based CMS (e.g., track assignment changes, new shunting activities, train consist updates), with their correct propagation to the TMS being monitored. The demonstration also involved creating or modifying a TCR directly within the TMS and verifying its successful transmission in both the national and local yard-based CMS.

For the **validation phase** and as closing activity of the validation event, quantitative and qualitative feedback was collected using a questionnaire with a group of questions. The questionnaire was answered by the end-users participating in the event, the timetable planners and dispatchers.

## 12.3. TRL validation of Demo 5.6

For carrying out the tests, the test strategy is to focus on the requirements as well as on usability and the need of system requirements and functionality. These test procedures include:

- **Functional tests:** these are defined based on the specific Test Cases.
- **Feature testing**: In this phase, any modification being done (because of the functional tests) by the developers is tested to ensure the functionality is implemented correctly.

The overall test procedure is to implement in the defined Test Frameworks to:

- Verify, given an input, e.g., if a JSON message is correctly created with the correct format and expected information to be processed via the interfaces.
- Verify the result, e.g., messages received, GUI snapshots indicating sending or receipt of messages, showing changes in application GUI.

The objectives of the testing activities are:

- verifying that the requirements are met;
- evaluate results of other activities such as requirements, Use Cases, design and code (where applicable);
- find and prevent defects; and
- report the defects.

The verification of the defined use cases in the deliverable “Deliverable D4.1 Integration of Planning Systems” was performed during the validation event organized in an online format. The event took place on the 10$^{th}$ of April 2026 together with the validation of the Demos 7.3 and 18.3. Part of the use cases were also demonstrated in a separated validation event held on the 15$^{th}$ of April 2026, together with Demo 12.7. For the propose of the validation, four end-users were present with a background of time tabling and dispatching. All of them have previous experience working with the Portuguese railway infrastructure, for the national infrastructure manager

company.

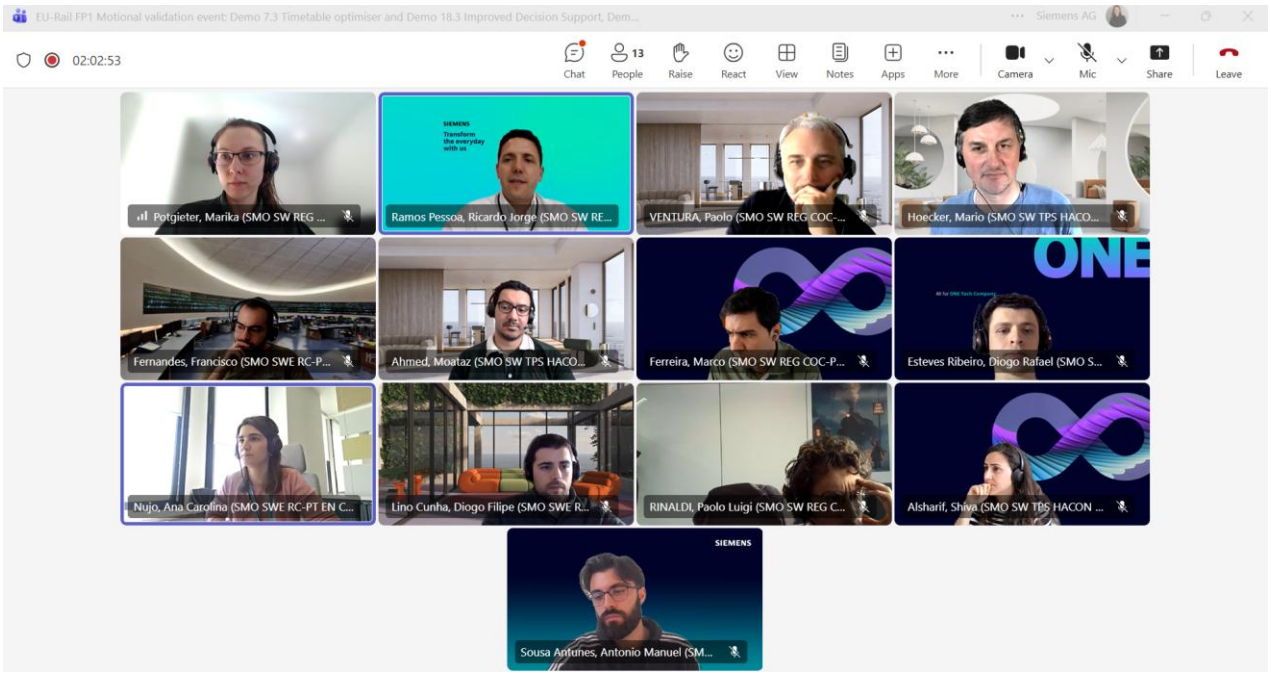



**Figure 12.2 – Validation event meeting**

Besides them, other system engineers and project collaborators have also participated in the event. The end-users had no previous experience in using our CMS tool and were given an overview to the tool, before the presentation of the use-cases. Before the validation event, a document was also provided with training information on the tool and on the use cases.

To move beyond technical verification (TRL4) and validate Demo 5.6 at a TRL6 level, the validation activities focused on user interaction, system integration, and the use of real-world operational data. This approach was crucial to demonstrate the prototype's functionality in a relevant environment and to gather feedback from actual end-users, ensuring its practical applicability as a beta-version.

While initial functional and feature tests confirmed the technical integrity of the interfaces, the TRL6 validation demonstrated feasibility of scenarios on a more user centred perspective. The validation events on April 10$^{th}$ and April 15$^{th}$, 2026, were specifically designed to simulate real-world operational workflows. To achieve that historical timetabling information was used based on Norway rail information from 2024. For the Yard based CMS, Alnabru station has been selected.

To evaluate about the usability and value of the system, quantitative and qualitative feedback was collected during the validation event, using a questionnaire like the one already presented in this document for Demo 5.3. The questionnaire was answered by the end-users participating in the event.

## 12.4. Evaluation and results in Demo 5.6

This section presents the key findings and outcomes from the validation event for Demonstration 5.6, which focused on the integration of the Traffic Management System (TMS) with network

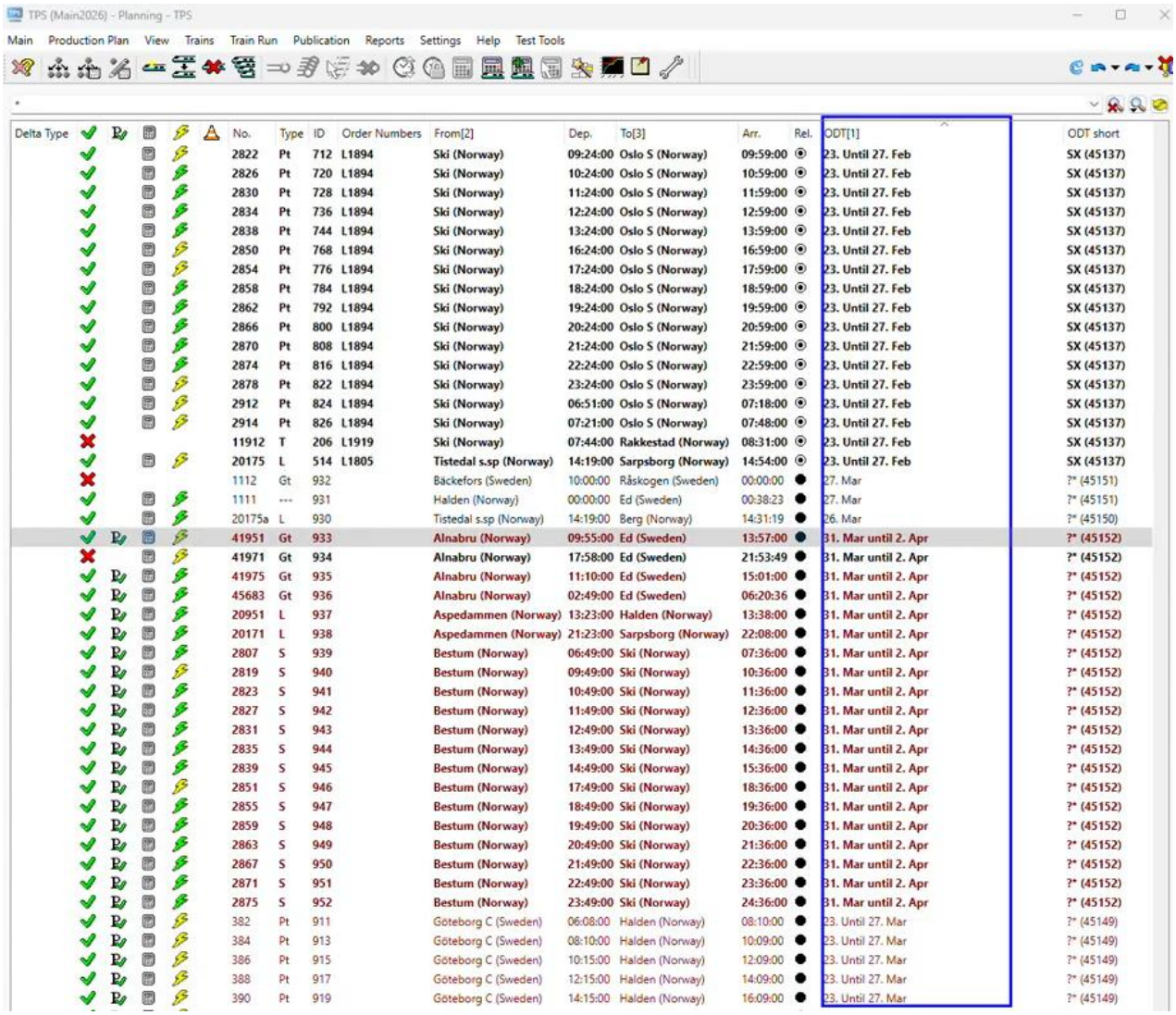
capacity planning. The validation successfully confirmed the achievement of our initial technical goals, particularly in establishing a robust link for planning information exchange between the Capacity Management System (CMS) and the TMS.

**Seamless Planning and Synchronization**

A core objective of Demo 5.6 was to demonstrate the flow of planning data between the national CMS and the TMS, ensuring that operational plans are consistent and up-to-date across both systems.

**National timetable overview in CMS**

Figure 12.3 provides a comprehensive view of the national timetable loaded into the CMS tool. This integrated timetable not only displays train paths within the Norwegian rail network but also highlights cross-border trains extending into Ed station in Sweden. It's important to note that the timetable extends beyond the current day (March 31st), covering a specified Operational Day Type (ODT) period, which is essential for proactive capacity management.

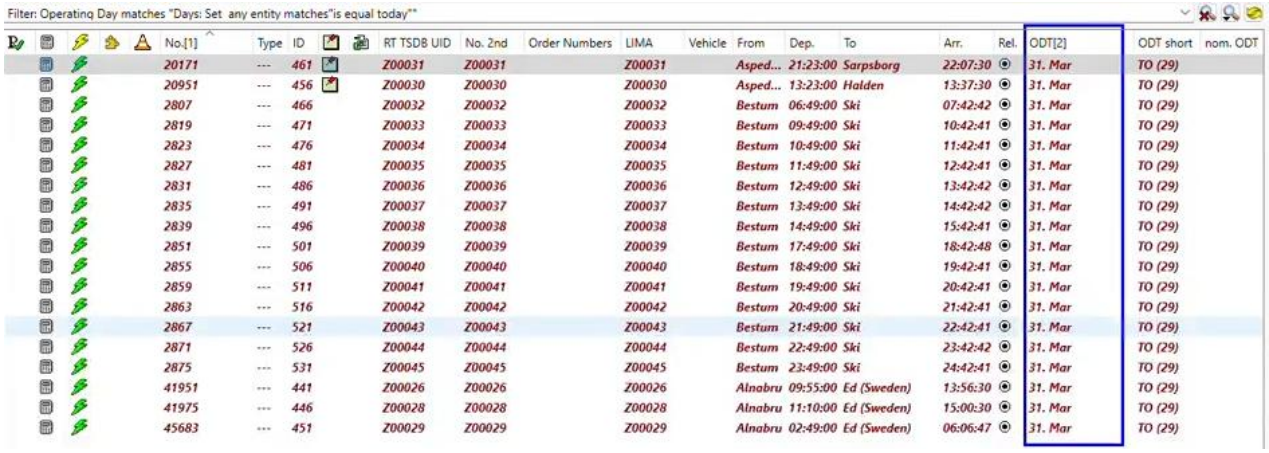



| Delta Type | No. | Type | ID | Order Numbers | From[2] | Dep. | To[3] | Arr. | Rel. | ODT[1] | ODT short |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2822 | Pt | 712 | L1894 | Ski (Norway) | 09:24:00 | Oslo S (Norway) | 09:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2826 | Pt | 720 | L1894 | Ski (Norway) | 10:24:00 | Oslo S (Norway) | 10:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2830 | Pt | 728 | L1894 | Ski (Norway) | 11:24:00 | Oslo S (Norway) | 11:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2834 | Pt | 736 | L1894 | Ski (Norway) | 12:24:00 | Oslo S (Norway) | 12:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2838 | Pt | 744 | L1894 | Ski (Norway) | 13:24:00 | Oslo S (Norway) | 13:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2850 | Pt | 768 | L1894 | Ski (Norway) | 16:24:00 | Oslo S (Norway) | 16:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2854 | Pt | 776 | L1894 | Ski (Norway) | 17:24:00 | Oslo S (Norway) | 17:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2858 | Pt | 784 | L1894 | Ski (Norway) | 18:24:00 | Oslo S (Norway) | 18:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2862 | Pt | 792 | L1894 | Ski (Norway) | 19:24:00 | Oslo S (Norway) | 19:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2866 | Pt | 800 | L1894 | Ski (Norway) | 20:24:00 | Oslo S (Norway) | 20:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2870 | Pt | 808 | L1894 | Ski (Norway) | 21:24:00 | Oslo S (Norway) | 21:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2874 | Pt | 816 | L1894 | Ski (Norway) | 22:24:00 | Oslo S (Norway) | 22:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2878 | Pt | 822 | L1894 | Ski (Norway) | 23:24:00 | Oslo S (Norway) | 23:59:00 | | 23. Until 27. Feb | SX (45137) |
| | 2912 | Pt | 824 | L1894 | Ski (Norway) | 06:51:00 | Oslo S (Norway) | 07:18:00 | | 23. Until 27. Feb | SX (45137) |
| | 2914 | Pt | 826 | L1894 | Ski (Norway) | 07:21:00 | Oslo S (Norway) | 07:48:00 | | 23. Until 27. Feb | SX (45137) |
| | 11912 | T | 206 | L1919 | Ski (Norway) | 07:44:00 | Rakkestad (Norway) | 08:31:00 | | 23. Until 27. Feb | SX (45137) |
| | 20175 | L | 514 | L1805 | Tistedal s.sp (Norway) | 14:19:00 | Sarpsborg (Norway) | 14:54:00 | | 23. Until 27. Feb | SX (45137) |
| | 1112 | Gt | 932 | | Bäckefors (Sweden) | 10:00:00 | Råskogen (Sweden) | 00:00:00 | | 27. Mar | ?* (45151) |
| | 1111 | --- | 931 | | Halden (Norway) | 00:00:00 | Ed (Sweden) | 00:38:23 | | 27. Mar | ?* (45151) |
| | 20175a | L | 930 | | Tistedal s.sp (Norway) | 14:19:00 | Berg (Norway) | 14:31:19 | | 26. Mar | ?* (45150) |
| | 41951 | Gt | 933 | | Alnabru (Norway) | 09:55:00 | Ed (Sweden) | 13:57:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 41971 | Gt | 934 | | Alnabru (Norway) | 17:58:00 | Ed (Sweden) | 21:53:49 | | 31. Mar until 2. Apr | ?* (45152) |
| | 41975 | Gt | 935 | | Alnabru (Norway) | 11:10:00 | Ed (Sweden) | 15:01:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 45683 | Gt | 936 | | Alnabru (Norway) | 02:49:00 | Ed (Sweden) | 06:20:36 | | 31. Mar until 2. Apr | ?* (45152) |
| | 20951 | L | 937 | | Aspedammen (Norway) | 13:23:00 | Halden (Norway) | 13:38:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 20171 | L | 938 | | Aspedammen (Norway) | 21:23:00 | Sarpsborg (Norway) | 22:08:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2807 | S | 939 | | Bestum (Norway) | 06:49:00 | Ski (Norway) | 07:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2819 | S | 940 | | Bestum (Norway) | 09:49:00 | Ski (Norway) | 10:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2823 | S | 941 | | Bestum (Norway) | 10:49:00 | Ski (Norway) | 11:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2827 | S | 942 | | Bestum (Norway) | 11:49:00 | Ski (Norway) | 12:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2831 | S | 943 | | Bestum (Norway) | 12:49:00 | Ski (Norway) | 13:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2835 | S | 944 | | Bestum (Norway) | 13:49:00 | Ski (Norway) | 14:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2839 | S | 945 | | Bestum (Norway) | 14:49:00 | Ski (Norway) | 15:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2851 | S | 946 | | Bestum (Norway) | 17:49:00 | Ski (Norway) | 18:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2855 | S | 947 | | Bestum (Norway) | 18:49:00 | Ski (Norway) | 19:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2859 | S | 948 | | Bestum (Norway) | 19:49:00 | Ski (Norway) | 20:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2863 | S | 949 | | Bestum (Norway) | 20:49:00 | Ski (Norway) | 21:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2867 | S | 950 | | Bestum (Norway) | 21:49:00 | Ski (Norway) | 22:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2871 | S | 951 | | Bestum (Norway) | 22:49:00 | Ski (Norway) | 23:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 2875 | S | 952 | | Bestum (Norway) | 23:49:00 | Ski (Norway) | 24:36:00 | | 31. Mar until 2. Apr | ?* (45152) |
| | 382 | Pt | 911 | | Göteborg C (Sweden) | 06:08:00 | Halden (Norway) | 08:10:00 | | 23. Until 27. Mar | ?* (45149) |
| | 384 | Pt | 913 | | Göteborg C (Sweden) | 08:10:00 | Halden (Norway) | 10:09:00 | | 23. Until 27. Mar | ?* (45149) |
| | 386 | Pt | 915 | | Göteborg C (Sweden) | 10:15:00 | Halden (Norway) | 12:09:00 | | 23. Until 27. Mar | ?* (45149) |
| | 388 | Pt | 917 | | Göteborg C (Sweden) | 12:15:00 | Halden (Norway) | 14:09:00 | | 23. Until 27. Mar | ?* (45149) |
| | 390 | Pt | 919 | | Göteborg C (Sweden) | 14:15:00 | Halden (Norway) | 16:09:00 | | 23. Until 27. Mar | ?* (45149) |

**Figure 12.3 – A sample of the national timetable within the CMS, illustrating both domestic and cross-border train movements extending over a defined Operational Day Type (ODT) period**

**Synchronized Operational Plan in TMS**

The successful synchronization between the CMS and TMS is further evidenced by Figure 12.4. This image displays the next 24 hours of the operational plan as seen within the TMS, directly reflecting the data transferred from the CMS. This synchronization is vital for traffic managers, providing them with the most current operational picture to guide their decision-making.



Filter: Operating Day matches "Days: Set any entity matches"is equal today""

| No.[1] | Type | ID | RT TSDB UID | No. 2nd | Order Numbers | LIMA | Vehicle | From | Dep. | To | Arr. | Rel. | ODT[2] | ODT short | nom. ODT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20171 | --- | 461 | Z00031 | Z00031 | | Z00031 | | Asped... | 21:23:00 | Sarpsborg | 22:07:30 | | 31. Mar | TO (29) | |
| 20951 | --- | 456 | Z00030 | Z00030 | | Z00030 | | Asped... | 13:23:00 | Halden | 13:37:30 | | 31. Mar | TO (29) | |
| 2807 | --- | 466 | Z00032 | Z00032 | | Z00032 | | Bestum | 06:49:00 | Ski | 07:42:42 | | 31. Mar | TO (29) | |
| 2819 | --- | 471 | Z00033 | Z00033 | | Z00033 | | Bestum | 09:49:00 | Ski | 10:42:41 | | 31. Mar | TO (29) | |
| 2823 | --- | 476 | Z00034 | Z00034 | | Z00034 | | Bestum | 10:49:00 | Ski | 11:42:41 | | 31. Mar | TO (29) | |
| 2827 | --- | 481 | Z00035 | Z00035 | | Z00035 | | Bestum | 11:49:00 | Ski | 12:42:41 | | 31. Mar | TO (29) | |
| 2831 | --- | 486 | Z00036 | Z00036 | | Z00036 | | Bestum | 12:49:00 | Ski | 13:42:42 | | 31. Mar | TO (29) | |
| 2835 | --- | 491 | Z00037 | Z00037 | | Z00037 | | Bestum | 13:49:00 | Ski | 14:42:42 | | 31. Mar | TO (29) | |
| 2839 | --- | 496 | Z00038 | Z00038 | | Z00038 | | Bestum | 14:49:00 | Ski | 15:42:41 | | 31. Mar | TO (29) | |
| 2851 | --- | 501 | Z00039 | Z00039 | | Z00039 | | Bestum | 17:49:00 | Ski | 18:42:48 | | 31. Mar | TO (29) | |
| 2855 | --- | 506 | Z00040 | Z00040 | | Z00040 | | Bestum | 18:49:00 | Ski | 19:42:41 | | 31. Mar | TO (29) | |
| 2859 | --- | 511 | Z00041 | Z00041 | | Z00041 | | Bestum | 19:49:00 | Ski | 20:42:41 | | 31. Mar | TO (29) | |
| 2863 | --- | 516 | Z00042 | Z00042 | | Z00042 | | Bestum | 20:49:00 | Ski | 21:42:41 | | 31. Mar | TO (29) | |
| 2867 | --- | 521 | Z00043 | Z00043 | | Z00043 | | Bestum | 21:49:00 | Ski | 22:42:41 | | 31. Mar | TO (29) | |
| 2871 | --- | 526 | Z00044 | Z00044 | | Z00044 | | Bestum | 22:49:00 | Ski | 23:42:42 | | 31. Mar | TO (29) | |
| 2875 | --- | 531 | Z00045 | Z00045 | | Z00045 | | Bestum | 23:49:00 | Ski | 24:42:41 | | 31. Mar | TO (29) | |
| 41951 | --- | 441 | Z00026 | Z00026 | | Z00026 | | Alnabru | 09:55:00 | Ed (Sweden) | 13:56:30 | | 31. Mar | TO (29) | |
| 41975 | --- | 446 | Z00028 | Z00028 | | Z00028 | | Alnabru | 11:10:00 | Ed (Sweden) | 15:00:30 | | 31. Mar | TO (29) | |
| 45683 | --- | 451 | Z00029 | Z00029 | | Z00029 | | Alnabru | 02:49:00 | Ed (Sweden) | 06:06:47 | | 31. Mar | TO (29) | |

**Figure 12.4 – The synchronized operational plan for the next 24 hours, as displayed within the Traffic Management System (TMS)**

**Visualising and Managing Restrictions in the TMS**

Another critical aspect of Demo 5.6 was to enhance the visualization and management of operational restrictions within the TMS, thereby empowering traffic dispatchers to identify and address potential issues proactively.

Figures 12.5 and 12.6 illustrate how restrictions are presented within the TMS system. Figure 12.5, showing the TMS Infrastructure View, provides a geographical representation of these restrictions. This visual aid is invaluable for traffic dispatchers, allowing them to quickly identify specific points on the infrastructure where operational constraints are present.

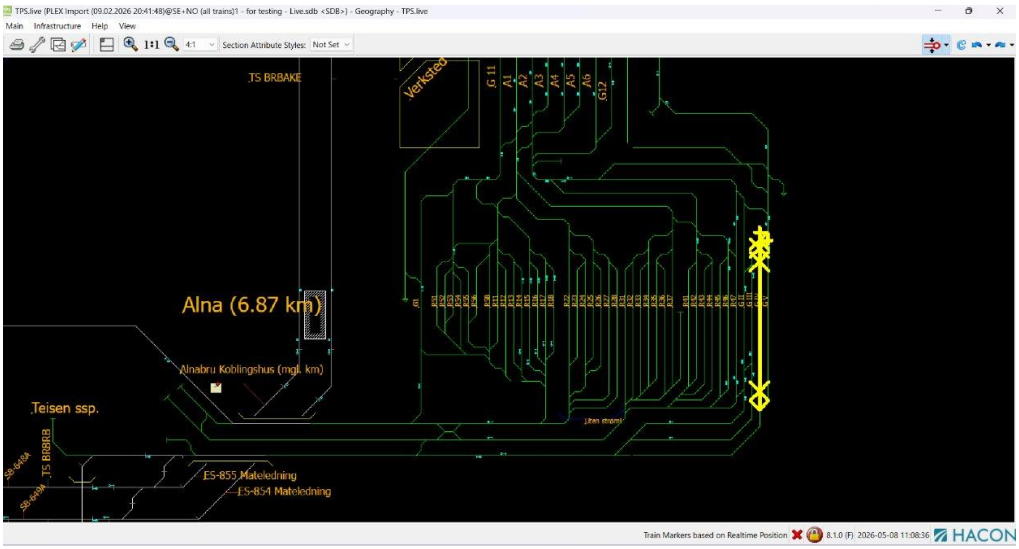



**Figure 12.5 – TMS Infrastructure View, highlighting operational restrictions directly on the railway network layout.**

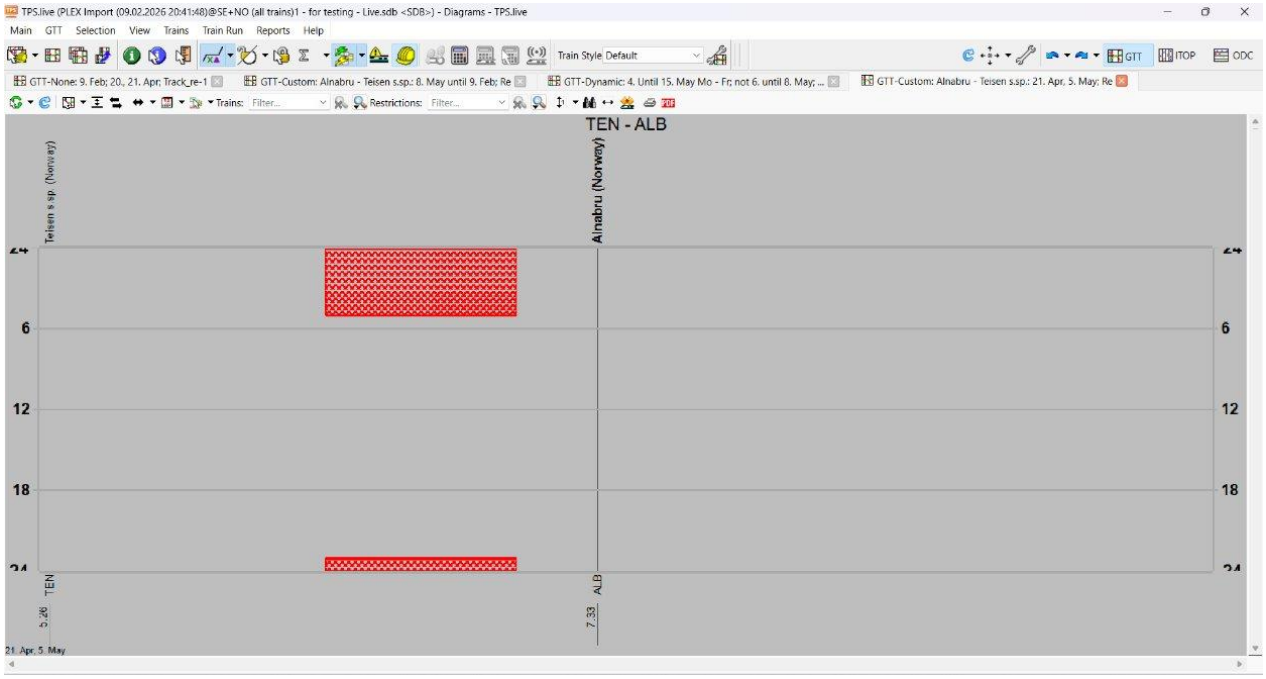



**Figure 12.6 – GTT (Graphical Train Timetable) View within the TMS, illustrating how operational restrictions are displayed in a temporal context**

**End-User Feedback and Evaluation**

To assess the practical utility and user acceptance of the demonstrated functionalities, end-users were invited to complete a questionnaire at the conclusion of the validation event. The aggregated results of this feedback are presented in Table 12.1.

**Table 12.1 – Summary of end-user feedback from the validation event questionnaire**

| Question\Participant | #1 | #2 | #3 | #4 | #5 |
|---|---|---|---|---|---|
| Overall, how useful do you find the functionalities demonstrated today for the daily work of a timetable planner/dispatcher? | (5) Extremely useful | (5) Extremely useful | (4) Very useful | (2) Slightly useful | (4) Very useful |
| How clear and easy to understand were the demonstration use cases presented today? | (4) Clear | (3) Neutral | (5) Very clear | (3) Neutral | (4) Clear |
| How well do you think the demonstrated processes address current challenges in managing railway capacity and planning? | (4) Very well | (4) Very well | (4) Very well | (3) Moderately well | (4) Very well |

The collection of feedback taken from the open text questions provided important suggestions and improvements for future work. The result is summarized in the next section.

**Most Valuable Aspect or Feature**
The participants consistently highlighted the automation and optimization capabilities as the most valuable aspects.

- Speed and Efficiency: The "speed of processing the new timetables" and the "simple way to add restrictions" were praised.
- Timetable Optimization: "Timetable optimization" in general was a key highlight.
- Automatic Repair: The "Algorithm for automatic repair of timetables in short-term timetable planning" was noted as useful and a "scientific advance."

**Areas for Improvement or Further Development**
Feedback on areas for improvement primarily focused on user experience, flexibility, and clarity of information.

- Outcome Information: One user suggested providing "more information for the user in terms of outcome like some kind of 'this new timetable saves x time on this trip' or 'this new timetable adds x time in stop time'."
- User Decision Power: The need for "ability to give decision power to the users despite all the automatism" and ensuring flexibility so "each customer should be able to define to what degree they want to fully rely on automatism" was emphasized.
- User-Friendliness/Graphics: Improvements in "graphics, more user-friendly" interfaces were suggested.

Clarity of Research Aims: One participant found "demonstration 14.3 was more unclear in what the research project was aiming to deliver in terms of producing new knowledge."

**Integration with Existing Workflows/Tools (Challenges/Benefits)**
The responses here leaned heavily towards the benefits of automation and optimization, with some consideration for client adaptation:

- Automation as Integration Point: One user plans to "keep focusing on the automation part - reduce human error and make optimal decision quick. that is the best integration point in current tools."
- Optimization based on Conditions: The "Capacity to optimize train routes based on several conditions instead of manually choose" was seen as a significant benefit.
- TSR Benefits: The functionalities are considered "very beneficial" for TSR (Train Slot Request) processes.

**Other Comments or Suggestions**
These comments offered practical advice on presentation and interface design, acknowledging the user base:

- Workshop Presentation: A suggestion was made to "see the 3 windows during the demo" for better understanding.
- Initial Context: One user noted that "the context initial part could be better - I missed a brief explanation on the TPS Live interface. To better understand the user workflow this kind of context is important."

- User Interface Simplicity: A crucial suggestion was to "keep in mind that most clients are dinosaurs, so keep in mind to have a simple and easy-going interface."

Overall, the feedback indicates a strong appreciation for the automation and optimization capabilities, with clear requests for more user-friendly interfaces, better outcome transparency, and flexible control over automated processes. These insights are very valuable for refining the demonstrated functionalities and their integration into real-world railway planning.

**Real-World Impact**

The real-world impact resulting from findings of demonstration 5.6 is the following:

- Facilitated operational feedback: A key impact is facilitating a feedback loop that provides operational information from the Traffic Management System (TMS) to the Capacity Management System (CMS). This ensures that capacity planning is informed by current operational realities, leading to more accurate and adaptable plans.
- Enhanced Data Exchange: The demonstration supports crucial data exchange between the TMS and local or national CMS, which is vital for coordinated planning and management across different levels of the railway network. This includes:
  - CMS Capacity Plans being sent to TMS.
  - New or changed local plans from yard-based CMS being sent to TMS.
  - New or changed operational TCRs in TMS being sent to national CMS.
  - New or changed operational TCRs in TMS being sent to local, yard-based CMS.
- Handling operational restrictions: User feedback highlighted the "simple way to add restrictions." The intuitive interface for creating new operational restrictions directly in the user interface of the TMS has a significant real-world impact in streamlining and the process of disruption management. This reduces manual effort and improves efficiency.

**Future Work**

Building on the foundational data exchange established in this deliverable, future work should focus on deepening the analytical and collaborative capabilities. The following recommendations outline areas for expansion that would enhance the value delivered:

- **Automated Deviation Detection and Pattern Analysis.** Future development should introduce a dedicated deviation detection and pattern analysis capability, enabling a systematic identification and tracking of recurring discrepancies between planned timetables and actual train movements over time. Rather than responding to individual operational disruptions in isolation, this capability would allow the recognition of patterns and trends.
- **Historical Performance Feedback for Timetable Refinement.** A natural and highly valuable extension of the current integration work would be storage and processing of aggregated historical operational data. This would enable planners to analyse long-term performance trends across the network, identify systemic bottlenecks, and validate or revise the assumptions that underpin their capacity planning decisions. The importance of this capability lies in its ability to close the feedback loop between operational execution and strategic planning in a meaningful and sustained way. Over successive planning cycles, infrastructure managers would benefit from continuously improving timetable quality, more accurate capacity utilisation assessments, and a stronger evidence base for infrastructure investment decisions.

- **Railway Undertaking Visibility into Operational Feedback.** Future work should also explore the controlled and selective sharing of relevant operational feedback data with Railway Undertakings. Railway Undertakings have a direct commercial and operational interest in understanding how their services perform against planned timetables, where recurring delays originate, and how capacity constraints affect their operations. By developing appropriate data sharing frameworks and access controls, infrastructure managers could provide Railway Undertakings with targeted performance insights that support better operational planning, more informed commercial decision-making, and more productive dialogue during the capacity allocation process.

# 13. Demo 5.7 – Integration of network capacity planning with yard and station capacity planning

For the Demo 5.7, HACON focused on the development of a demonstration supporting the WP5 objectives for

- TE 2: Improved capacity allocation using rolling planning and TTR
- TE 6: Integration of TMS with a) yard capacity planning and b) station capacity planning

The development was based on the results of the activities in Task 5.2.4 (achieving TRL 6) to show the integration of national CMS with station/yard-based (local) CMS to ensure overall and real-time alignment of local and national planning.

The development for Demo 5.7 covers the following WP3 use case:

- Data exchange between national capacity management/planning system (national CMS) and local, yard-based capacity management/planning system (local CMS) (UC-FP1-WP3-6)

In accordance with MOTIONAL D4.1, the scope of functionality addressed by the demonstrations is reflected by the following topics:

1. CMS sends new or changed capacity plan to local, yard-based CMS.
2. Local, yard-based CMS receives new or changed capacity plan from the CMS.
3. Local, yard-based CMS sends new or changed local plan to the CMS.
4. CMS receives new or changed local plan from the local, yard-based CMS.

In the Demo 5.7, the national capacity management system (CMS) and the yard- or depot-based 'local' CMS exchange relevant capacity plan information as illustrated in the system overview presented in Figure 13.1.

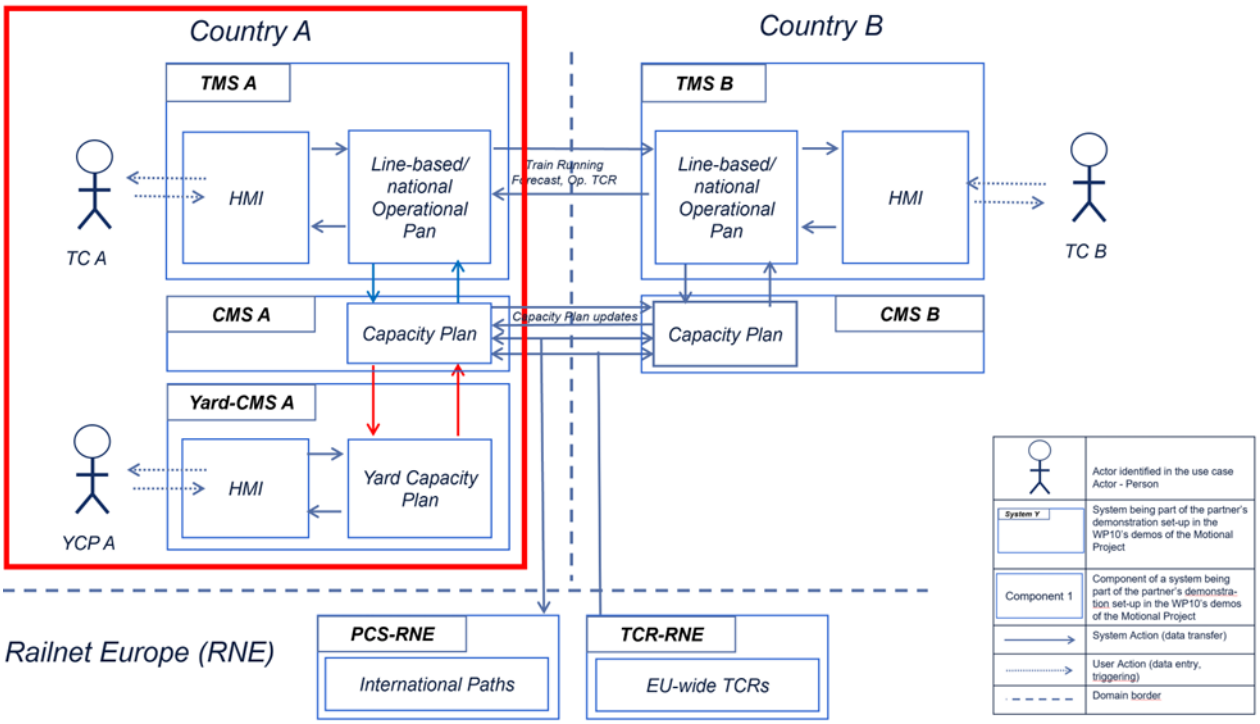



**Figure 13.1 – Overview of the system architecture for Demo 5.7**

The Yard Capacity (Management) System (YCS) is a system focused on the detailed, localised management of track and platform occupancy within yards, sidings, and stations. The YCS is of relevance in large and complex freight yards and passenger depots, where the volume and variety of rolling stock movements demand a dedicated system capable of handling fine-grained operational detail.

## 13.1. Method and development for Demo 5.7

The development of Demo 5.7 was based on the results of activities in Subtask 5.2.4, which aimed at achieving TRL 6. This demonstration focuses on the crucial communication between national network-level Capacity Management Systems (CMS) and local, yard-based or station-based capacity planning systems. This communication is essential for ensuring overall coherence between local and national planning, bridging the gap between strategic network-wide capacity allocation and the detailed planning within specific railway stations, yards, and sidings.

Historically, planning at the national level and at local yards/stations has often been disconnected, leading to inefficiencies, undetected conflicts, and suboptimal use of infrastructure. Demo 5.7 addresses this by developing and demonstrating robust mechanisms for seamless data exchange between these two planning layers. This foundational work directly contributes to a more harmonised and effective planning approach, ensuring that local planning decisions are reflected in national plans and vice versa.

The scope of the functionality addressed by the demonstrations follows the Use Cases and Requirements as described in 'Deliverable 4.1 Integration of Planning Systems'. As such, the main components involved are the national CMS and the local, yard-based/station-based CMS, with a specific focus on the interfaces and data exchange protocols between them.

The implementation comprised the development and integration of:

- Bidirectional Data Exchange Interfaces: Establishing robust interfaces for the exchange of critical planning data between the national CMS and local CMS.
- Consistency Maintenance Mechanisms: Implementing processes to ensure that changes made at one planning level are accurately and consistently reflected at the other, preventing discrepancies.
- Enhanced Local-Global Planning Alignment: Enabling a more coordinated approach to capacity planning, where local constraints are considered in network-wide decisions, and national plans guide local plans.

For the different use cases, the inputs were adjusted accordingly. For instance, when the national CMS generates a new or updated capacity plan, this information is communicated to the relevant local CMS. The local CMS imports this plan, adjusting its detailed yard or station plan to align with the national plan. Conversely, any significant changes or constraints arising at the local level are communicated back to the national CMS.

The test scenarios were designed to reflect real-world planning scenarios, such as adding new shunting movements, planning train arrivals and departures given yard capacity, and improving the visibility of locally created restrictions at the national level. These scenarios aimed to demonstrate how the integrated system can effectively manage and respond to such events, highlighting the benefits of continuous alignment between national and local capacity planning.

The following use cases were central to the development and demonstration of the integration between the national CMS and local, yard-based/station-based CMS.

The use cases focused on establishing and optimising the mechanisms for data exchange between the national CMS and local, yard-based or station-based CMS. The development ensured that these two planning layers can effectively communicate and synchronise their capacity plans, leading to an efficient overall railway planning approach. This bidirectional exchange is crucial for maintaining alignment between network-wide strategic planning and detailed local planning.

Specifically, the development encompassed the following key aspects of data exchange:

**CMS Sends New or Changed Capacity Plan to Local, Yard-Based CMS -** The national CMS is enabled to transmit its new or updated capacity plan to the relevant local, yard-based CMS. This plan includes planned train paths, with scheduled arrival/departure times and tracks, and resource links (such as crew and rolling stock links) that affect specific yards or stations. This ensures that the local plan always remains aligned to the latest network-wide plan.

**Local, Yard-Based CMS Receives New or Changed Capacity Plan from the CMS -** The local, yard-based CMS is equipped to receive (import) the capacity plan sent by the national CMS. Upon receipt, the local system will automatically reflect the most recent national plan in its detailed track level views (e.g., track allocation, shunting schedules) in line with the most recent network-level changes.

**Local, Yard-Based CMS Sends New or Changed Local Plan to the CMS -** The local, yard-based CMS can export locally applied updates to the national CMS. The local plan may contain information

about planned track assignments, new shunting movements, and any locally applied constraints (such as capacity restrictions). The national CMS will use this input to determine how these changes impact the broader network plan. This feedback loop is vital for informing the national CMS about local planning decisions.

**CMS Receives New or Changed Local Plan from the Local, Yard-Based CMS -** The national CMS can import the locally applied changes sent by the yard-based CMS. This allows the national CMS to incorporate local planned details and identify potential impact of such local changes on the national capacity management plan. This ensures that national plans are always aligned with local planning decisions.

The successful implementation of this use cases significantly enhances the overall efficiency, reliability, and resilience of the railway network. By integrating local planning decisions into national-level plans and vice versa, railway infrastructure managers can achieve a more adaptive approach to capacity management. This leads to improved coordination, reduced misalignment between planning levels, early detection of conflicts caused by local changes, better utilisation of infrastructure resources, and ultimately, a more seamless and predictable railway planning across the entire network.

## 13.2. Demonstration planning of Demo 5.7

This section describes the planned and performed actions across each phase of the demonstration for Demo 5.7, focusing on the integration of national and local capacity management systems. The objective is to showcase the seamless data exchange between national-level and yard-based planning.

The **preparation phase** for Demo 5.7 focused on setting up the necessary environments, defining the scope, and preparing the data and test scenarios required to effectively demonstrate the integration between the national CMS and local, yard-based CMS.

The selected infrastructure covers part of the Norway national rail network. For the Yard scenarios, Alnabru freight yard was selected. Alnabru freight yard is located near Oslo central station. The infrastructure data model was imported to the CMS in the prepared testing environment.

During this phase historical data has been collected and prepared, including a set of train paths, TCRs, and resource links that would typically be communicated to a local yard. This plan reflects an example timetable for Norway the year 2024.

The **implementation phase** involved the actual development, configuration, and testing of the interfaces and functionalities required for Demo 5.7. Special effort was dedicated to the correct development of the user interface of the yard CMS and adapting it to show the necessary yard related information, such as track occupation and active restrictions as shown in Figure 13.2.

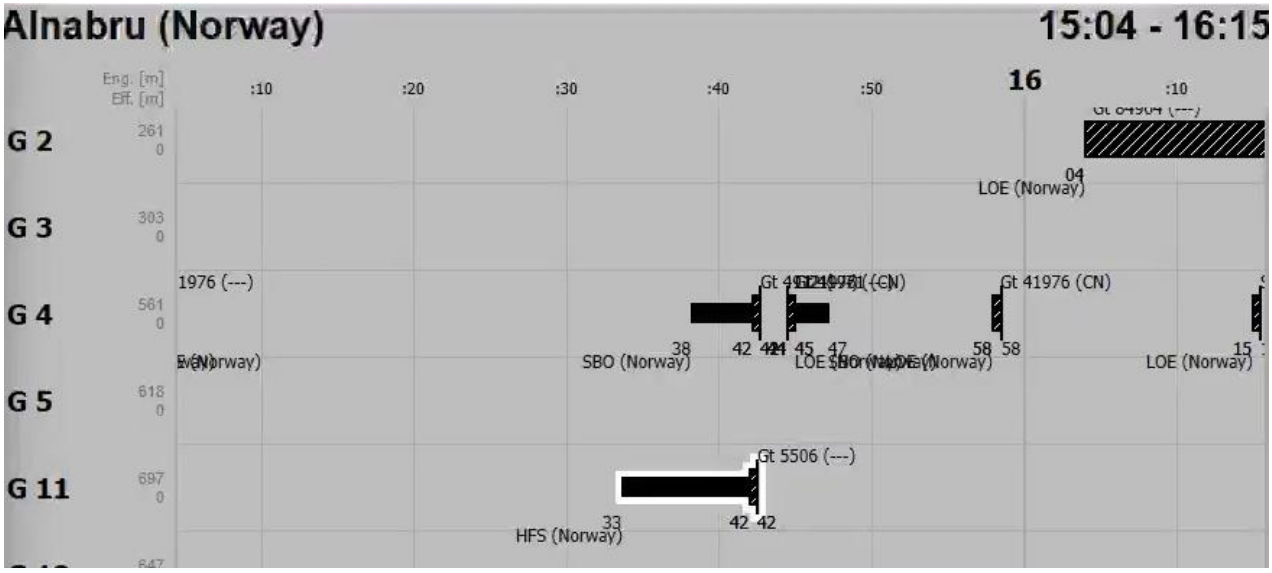



**Figure 13.2 – User interface of the Yard-based CMS**

During **execution phase** the different use cases were deployed and executed in the testing environment, showcasing the integrated functionalities to relevant stakeholders.

The final timetable was loaded into the CMS system, and tests have shown how the information is presented in the Yard-Based CMS.

The **evaluation phase** assesses the success of Demo 5.7 against its objectives, identifies achievements, and outlines areas for future improvement.

For the functional verification, the actual outcomes of the demonstration scenarios were compared with the predefined expected outcomes. Also, an interface validation was performed to verify that all interfaces for data exchange function as designed, with correct data formats and successful transfer of data. With the data consistency check it was confirmed that data remains consistent and accurate across both the national and local CMS systems after exchange.

During the validation event, end-user feedback was collected from participating stakeholders to assess on the usability, effectiveness, and perceived benefits of the solution. This feedback will inform the identification of any remaining gaps or areas for further development and will contribute to improved efficiency of rail capacity planning.

## 13.3. TRL validation of Demo 5.7

For carrying out the tests, the test strategy is to focus on the requirements as well as on usability of system functionality. These test procedures include:

- **Functional tests:** these are defined based on the specific Test Cases.
- **End-to-end testing**: In this phase, any modification being done (because of the functional tests) by the developers is tested to ensure the functionality is implemented correctly.

The overall test procedure is to implement in the defined Test Frameworks to:

- Verify, given an input, e.g., if a message is correctly created with the correct format and expected information to be imported/exported via the interfaces.
- Verify the result, e.g., logs indicate that messages were received successfully and the user interface correctly reflects the necessary changes.

The objectives of the testing activities are:

- verifying that the requirements are met;
- identify defects and deviations from the specification; and
- document defects so that they can be reported for correction.

The verification of the defined use cases in the deliverable "Deliverable D4.1 Integration of Planning Systems" was done during the validation event that was held in Siemens Mobility Software Portugal facilities in Aveiro, Portugal. The event took place on the 18th of March 2026. For the purpose of the validation, three end-users were present in the room with experience of the operational control centre software and operational procedures used by the Portuguese railway Infrastructure Manager, see Figure 13.4.




**Figure 13.4 – Demo 5.7 validation event**

Besides the three participants who attended the session in-person, other system engineers and project collaborators also participated remotely during the event. The end-users had no previous experience in using our CMS tool, and were given an overview to the tool, before the presentation of the use-cases. Prior to the validation event, a document was also provided with training information on the tool and on the use cases.

As a closing activity of the validation event, quantitative and qualitative feedback was collected using a questionnaire. The questionnaire was like the one already presented in Demo 5.3 chapter of this document. The questionnaire was answered by all end-users present at the event.

## 13.4. Evaluation and results in Demo 5.7

This section details the practical application and validation of the Yard Coordination System (YCS) and its integration with the national Capacity Management System (CMS) during the validation event. Through a series of realistic scenarios, we demonstrated the systems' capabilities in conflict detection, resolution, and the efficient management of dynamic yard operations, including new shunting activities.

**Conflict Detection and Resolution in the Integrated YCS and National CMS**
A key focus of our validation was to showcase the seamless interplay between the local yard-based CMS (YCS) and the national CMS in identifying and resolving operational conflicts. The Interactive Track Occupation Plan (ITOP) view within the YCS proved to be an invaluable tool in this process, offering a dynamic and intuitive graphical representation of yard activities.

To illustrate this, we simulated a scenario at Alnabru station involving a conflict between a planned train movement and a local track allocation. Initially, Train 5811 was scheduled for departure from Alnabru to Ørstad at 8:51 PM, utilising track G4-S. However, a local yard-based CMS user, operating with a localized view, attempted to reserve the same track (G4-S) for a longer duration, from 8:00 PM until 11:30 PM. This action immediately triggered a conflict within the system as seen in Figures 13.5 and 13.6.

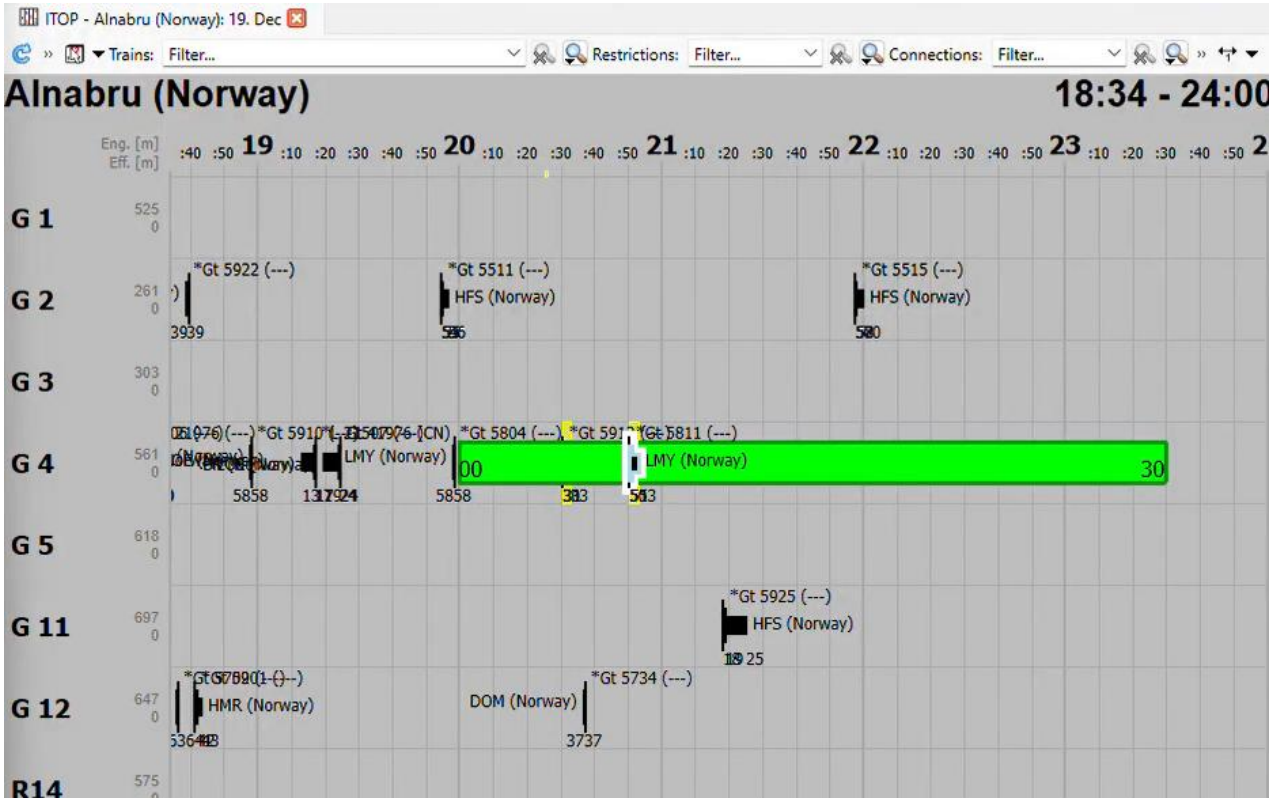



**Figure 13.5 – Interactive Track Occupation Plan (ITOP) view in the YCS showing a conflict**




**Figure 13.6 – Conflict detected as seen in the National CMS**

As depicted in Figure 13.5, the ITOP view provided an immediate visual alert of the overlapping schedules. Concurrently, the Train Planning View within the national CMS also detected this conflict, flagging it in its messages tab, thereby ensuring that both local and national planners were aware of the potential operational clash as seen in Figure 13.6.

The strength of the integrated system lies in its ability to facilitate collaborative resolution. With the national CMS offering a comprehensive network-wide perspective, planners could assess the broader impact of the local track allocation. In this instance, personnel operating the Yard, in coordination with the national CMS planner, adjusted the conflicting track allocation. The Yard user updated the track allocation, shifting its start time to 10:00 PM.

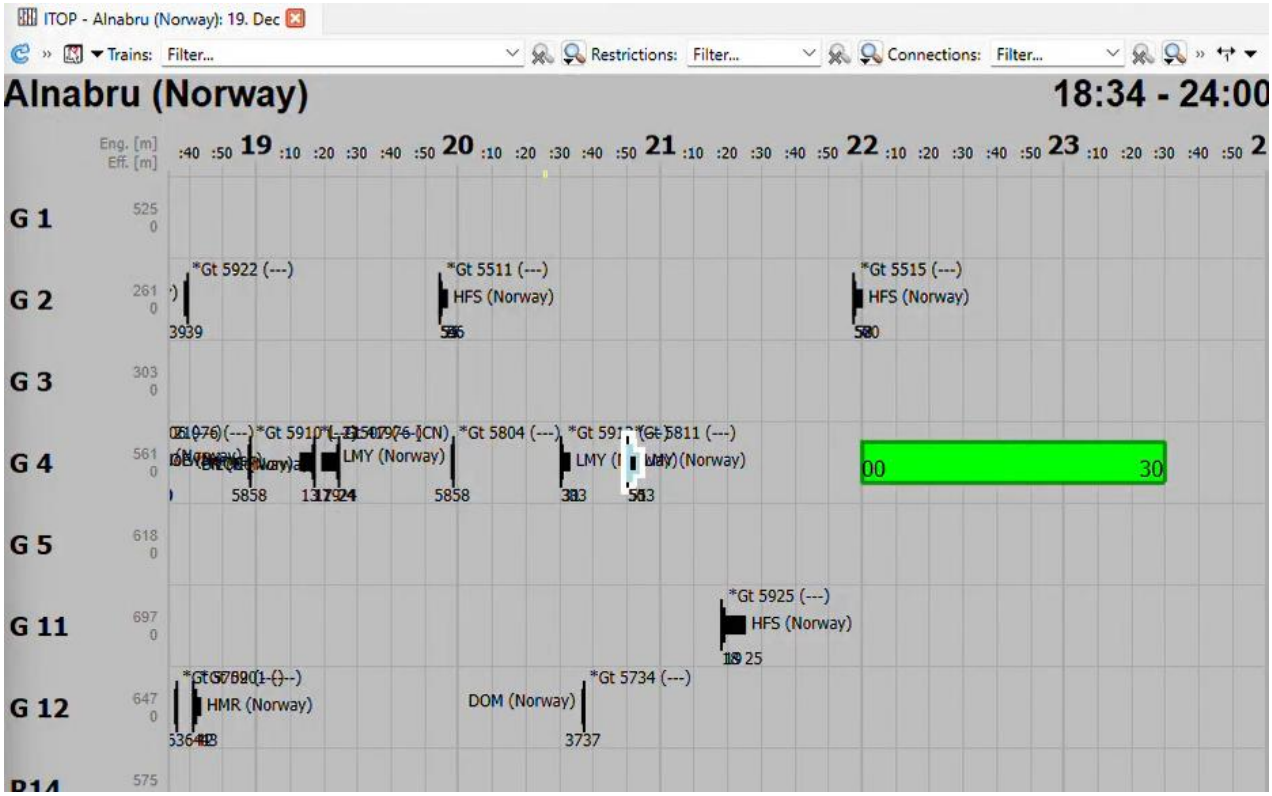



**Figure 13.7 – Interactive Track Occupation Plan (ITOP) view in the YCS after conflict resolution**

As shown in Figure 13.7, this adjustment immediately resolved the conflict. The ITOP view updated in real-time, confirming that the track allocation no longer interfered with Train 5811's planned movement. Crucially, this resolution was simultaneously reflected in both the national CMS and the local yard-based CMS, ensuring complete synchronization and coherence across all planning levels.

**Managing New Shunting Activities**

Beyond conflict resolution, the validation event also highlighted the YCS's capability to integrate and manage dynamic operational changes, such as new shunting activities, with the national CMS. This demonstrates the system's ability to maintain an accurate and up-to-date operational picture even amidst real-time yard movements.

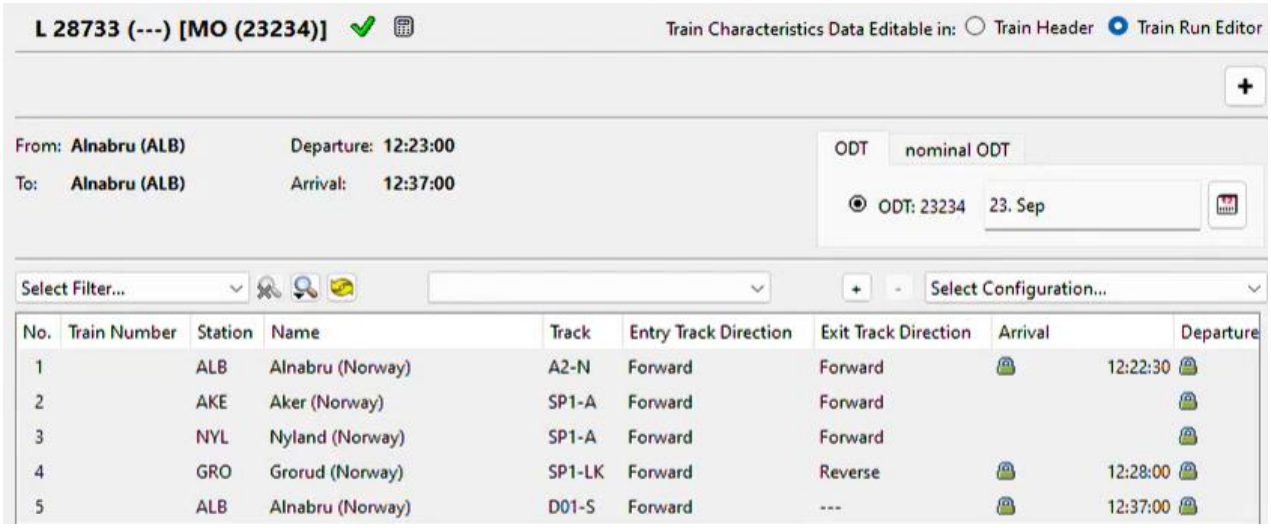



**Figure 13.8 – National CMS interface displaying the planning of a new shunting move**

Figure 13.8 illustrates how a newly planned shunting move, originating from the YCS, is seamlessly integrated and displayed within the national CMS. This view provides national planners with critical visibility into local yard activities that may have an impact on main line operations or overall network capacity.

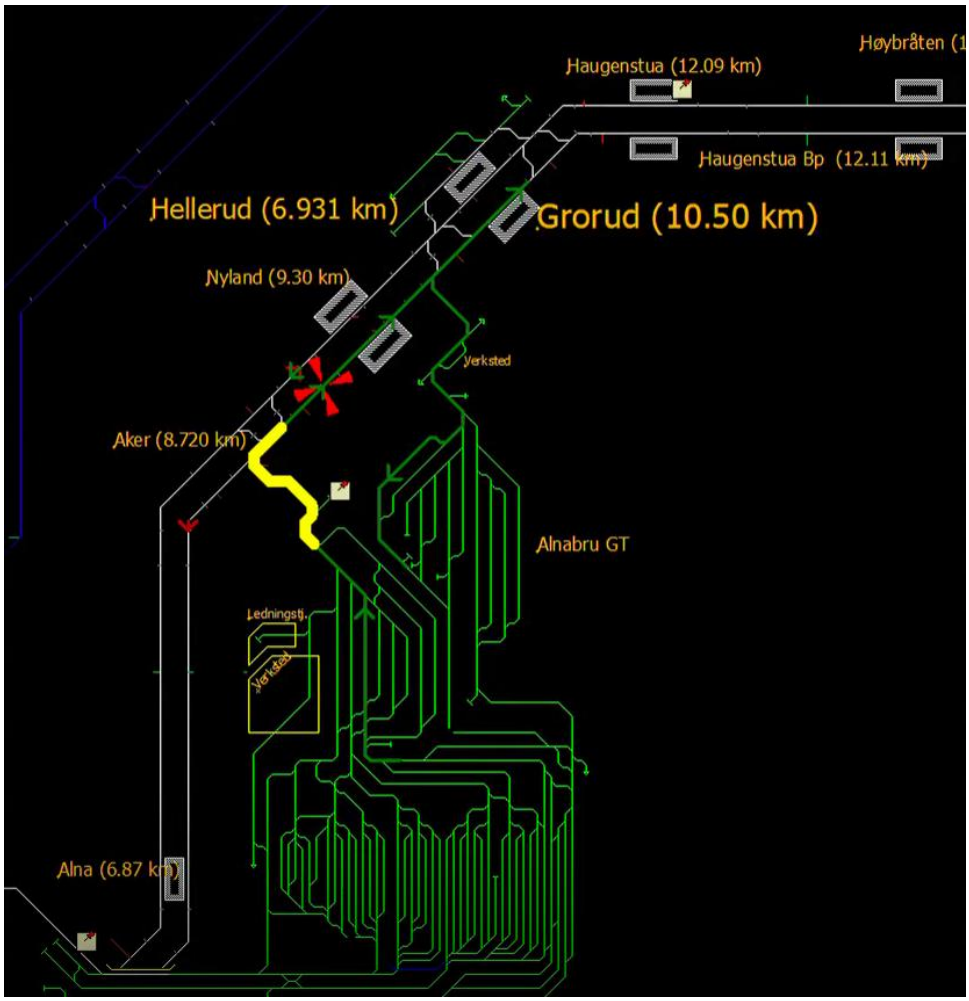



**Figure 13.9 – Conflict visible in the national CMS as a result of a new shunt move**

The graphical representation within the CMS infrastructure view, as seen in Figure 13.8, clearly signals the shunting move, allowing for informed decision-making and proactive management of potential interactions with other train movements. This integration ensures that local flexibility is maintained while preserving the integrity and safety of the wider rail network.

To evaluate the demonstrated solution during the validation event, a questionnaire was provided to the end users. The end users were able to answer all questions anonymously. The questionnaire included both closed questions and open-ended questions and the results were presented in Chapter 11.4 together with the results for Demo 5.5.

**Real-World Impact**

The real-world impact can be summarized as the following:

- Coherent Local and National Planning: The primary impact is ensuring overall and real-time alignment between local (yard/depot-based) and national capacity planning. This means that local planning changes are reflected in national plans, and vice versa, preventing discrepancies and improving network-wide efficiency.
- Enhanced Data Exchange: This demonstration focuses on specific data exchange scenarios between the national CMS and local, yard-based CMS, including:
  - CMS sending new or changed capacity plans to local, yard-based CMS.
  - Local, yard-based CMS receiving new or changed capacity plans from the CMS.
  - Local, yard-based CMS sending new or changed local plans to the CMS.
  - CMS receiving new or changed local plans from the local, yard-based CMS.
- Accommodation of Existing Workflows: The aim is to integrate these new functionalities directly within existing workflows and tools, leading to a more unified and efficient planning environment.

**Future Work**

Building upon the achievements of Demo 5.7, future work could explore several avenues:

- Refining interfacing protocols: Further development might involve evolving the protocols and mechanisms for data exchange between national and local CMS to ensure ongoing alignment to evolving reginal standards.
- Addressing challenges in integration: As highlighted in the user feedback, potential challenges in integrating with existing workflows and tools will need to be addressed through continued development and user feedback.
- Expanding scope of integration: Future work could explore integrating with other relevant systems or expanding the types of information exchanged to further enhance the coherence of planning at different levels.
- User experience for integrated systems: While not explicitly mentioned for Demo 5.7, the general feedback about user-friendliness and clear interfaces for integrated systems would likely apply here as well, suggesting future work in improving the user experience for planners interacting with these integrated systems.

# 14. Interaction with other Flagship Projects

Effective collaboration and interaction between Flagship Project 1 (FP1 Motional) and other Flagship Projects (FP3, FP5, FP6) were crucial for achieving broader program objectives. This cooperation was implemented and supported by having the same companies and the same players involved in both FPs or via respective meetings on dedicated topics for an exchange on, for example, standards, functions which are used or could be used by one FP and are developed by another FP.

**Collaboration between Flagship Projects**

Collaboration between FP1 and other FPs often involved the development of functionalities in one project that were then leveraged for wider demonstration and application in another. A notable example is the interaction between FP1 and FP5. Functionalities, such as Traffic Management, developed by entities like Hacon within one FP were often utilized by the other. For instance, the cross-border planning component and the integration of last-mile planning into timetable development were primarily developed in FP5 due to its stronger focus on freight operations, while the broader timetable planning developments resided within FP1. Conversely, the yard coordination system, developed within FP1 for traffic management, found practical application and demonstration within FP5. This reciprocal arrangement proved highly effective.

FP1 have had regular dialogue with FP5 about demonstrations performed in Malmö–Oslo/Alnabru corridor. At the Cross-border dissemination event 13 May 2026 in Stockholm, part of the event was focused on FP1 and FP5 demonstrations in this corridor and how they are connected. More detailed information about interaction and contribution between FP1 and FP5 is given below.

Demo 5.4 Collaborative yard capacity planning using the Yard Coordination System (YCS) had knowledge and information exchange with demos in FP5. Demos both in FP1 and FP5 had the railway corridor Malmö-Alnabru in focus. In FP5, Trafikverket have been working with concepts for data and information exchange, using the concept Railway Collaborative Decision Making (CDM). A cornerstone in the Railway CDM concept is the data sharing platform Deplide, developed by RISE, and enhanced in FP5 WP33. The Deplide platform is used also in YCS, both internally and to share data between YCS and Railway CDM. For example, one of the demonstrated test cases of UC-FP1-WP3-11 included visualizing arrival times for trains in Denmark, based on data in the Railway CDM platform, build in FP5. Thus, the connection between FP1 and FP5 contributed to YCS getting more accurate and updated information.

A general agreement for exchange at key milestones, including deliverable reviews, was established across all involved FPs, allowing for feedback loops between projects at specific points. However, it was observed that this cross-reading process was often time-consuming and frequently brought limited additional input, largely because founding members already maintained direct alignment. Consequently, for Wave 2 and Wave 3, the recommendation is to reduce the extent of this broad cross-reading, also because it's already established an alignment between the founding members. Future inter-project reviews should be limited to critical aspects where such detailed alignment is absolutely necessary, thereby optimising resource allocation.

**Interaction with the System Pillar**

The interaction with the System Pillar (SP) was a specific and highly structured aspect of FP1's

collaboration strategy, revealing its importance for architectural consistency. This involved regular meetings, initially bi-weekly during certain project phases, which then transitioned to larger monthly or quarterly exchange meetings. These sessions facilitated a critical two-way exchange of information: FP1 communicated developments, particularly within its traffic management and capacity management components, to ensure the SP was informed about innovation progress and could incorporate these insights into its architectural work. At the same time, FP1 received updates on the activities of the SP, especially those within Task 3, which directly impacted FP1's traffic and capacity management developments. Furthermore, FP1 partners actively participated in providing feedback on official SP documents, especially concerning architecture. Their input was considered highly relevant for the release of these documents, given their role in the subsequent implementation of the respective solutions.

The lessons learned from these inter-project and SP interactions will be a key instrument in refining future collaboration models, ensuring more efficient development cycles for subsequent program waves.

# 15. Conclusions

In this deliverable, the validation and evaluation of the seven demonstrations included in WP5 are presented. The aim is to ensure the target TRLs that allow the verification of the achievement of the goals of WP4 and WP5. All demonstrations aiming at improving the planning and communication processes when new information is given as, for example, ad hoc train paths, updated arrival/departure times, TCRs or other changes that need to be transferred between PCS, CMS and TMS, both locally, nationally and internationally. Regular dialogue with System Pillar and RailNetEurope has been a part of the work and also a special focus on Malmö–Oslo/Alnabru corridor with demonstrations performed in FP1 WP5, WP12 and FP5. Results from each demo are:

- In Demo 5.1, an interface solution is developed that connects the CMS with a centralised PCS. Five test cases were executed successfully, validating the full interaction workflow between the PCS simulator and the CMS.
- In Demo 5.2, a tool for identifying residual capacity for ad hoc train paths is developed. The tool can also be used to generate alternative train paths and evaluate them using simulation to support the planners' decision making. End users present for the validation event where in general positive and could agree on that a fully developed tool would meet their needs and allow to speed up the ad hoc planning process.
- During the validation of Demo 5.3, it was possible to demonstrate that the CMS (TPS.plan) supports bi-directional system-to-system integration with the RNE PCS for the exchange of international path requests and related capacity data, via both the PCS Integration Platform (web services) and the Telematics TSI CI.
- Demo 5.4 demonstrates how the developed operational planning system (YCS) for the tracks in an arrival/departure yard can be used to improve the planning of yard resources. It is also shown how the information exchange within the tool between line manager, yard manager and terminal manager leads to more efficient operations, reduced manual workload and stress.
- In Demo 5.5, it is demonstrated how the CMS generates a file compatible for uploading of Capacity Model data to the ECMT tool currently developed by RNE to improve the alignment of European capacity planning results. The messaging required for this purpose has been recently specified in the System Pillar Task 3 providing a first version of the specification.
- In Demo 5.6, a seamless integration of TMS with CMS is demonstrated, ensuring that operational plans are consistent and up-to-date across both systems. The successful implementation of this use case significantly enhances the overall efficiency and resilience of the railway network. Railway infrastructure managers can achieve a more harmonised and adaptive approach to capacity management, leading to improved punctuality, reduced disruptions, and better utilization of infrastructure.
- Demo 5.7 shows the integration of national CMS with station/yard-based (local) CMS to ensure overall and real-time alignment of local and national planning. Through a series of realistic scenarios, the systems' capabilities in conflict detection, resolution, and the efficient management of dynamic yard operations, including new shunting activities were successfully demonstrated.

The overall conclusions from D5.1 are that we now have an interface solution that can communicate cross-border train paths between PCS and CMS and we also have the possibility to generate cross-border train paths using residual capacity. We have an improved station/yard-

based planning to ensure overall and real-time alignment between local and national capacity planning that leads to more efficient operations. Also, the communication between TMS–CMS and between CMS–RNE PCS and CMS–ECMT are enhanced. An improved feedback loop between the TMS and the CMS ensures, for example, that capacity planning is informed by current operational realities, leading to more accurate and adaptable plans. The improved communication between CMS–RNE PCS improves the coordination of international train path requests which enhances cross-border planning and the communication between CMS–ECMT lays the foundation for a future, more coordinated, European capacity management system.

For future work, there is a need to continue with the progress towards deployment in operational use, which is the overarching objective. For example, there is a need to expand the use cases and investigate the integration of additional use cases or new scenarios to cover a broader spectrum of user needs. Also, there is a need to investigate the communication with other relevant systems and the need for expanding the types of information exchanged to further enhance the coherence of planning at different levels. The user-friendliness is also an area to study further since there is a need to improve the user experience for planners interacting with these integrated systems.

# 16. References

ERA (2012). Technical document. TAF TSI – Annex D.2: Appendix F – TAF TSI Data and Message Model. era_technical_document_taf-td-105_d_2_appendix_f.pdf

FP1-MOTIONAL (2023). Deliverable 3.1 - Mapping against scope, specification of technical enablers, high-level use cases, high-level requirements, high-level design for demonstrators in WPs 4-9. D03.1-Mapping-against-scope_-specification-of-technical-enablers_-high-level-use-cases.pdf

FP1-MOTIONAL (2024a). Deliverable 2.4 - Demonstration strategy. https://rail-research.europa.eu/wp-content/uploads/2025/05/MOTIONAL_D2.4-Demonstration-strategy-1.pdf

FP1-MOTIONAL (2024b). Deliverable 2.5 - Use cases for project demonstrations. https://rail-research.europa.eu/wp-content/uploads/2026/02/D2.5-UC-for-project-demonstrations.pdf

FP1-MOTIONAL (2024c). Deliverable 4.1 - Integration of planning systems. https://rail-research.europa.eu/wp-content/uploads/2026/03/MOTIONAL_D4.1.pdf

UIC (2013). UIC Code 406: Capacity. https://www.scribd.com/document/396917377/UIC-Leaflet-406