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Rail to Digital automated up to autonomous train operation

D39.7 – Integration Activities Report

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EXECUTIVE SUMMARY

The D39.7 "*Integration Activities Report*" presents the laboratory-based integration and validation activities undertaken to prepare the GoA4 system for its subsequent field deployment. Within the broader objectives of Work Package 39, the work addresses a central challenge for the introduction of autonomous railway operations: ensuring that the on-board subsystem, the Blues Train TCMS, and the signalling infrastructure are able to interact coherently, safely, and predictably before entering real-world railway environments. Conducting this integration work in controlled laboratory conditions is essential to reduce technical risk, verify subsystem compatibility, and enable repeatable testing of key functionalities associated with GoA4 automation. The need for this preparatory phase stems from the intrinsic complexity of autonomously operated trains, where nominal operation, degraded modes, and remote supervision scenarios must be managed seamlessly while still complying with signalling constraints and established safety requirements.

The activities reported here follow a progressive scientific and technical approach, grounded in reproducibility and iterative verification. Two dedicated laboratory environments were established to replicate the operational ecosystem of the demonstrator, allowing to interconnect the GoA4 related on-board subsystems with both the TCMS and the signalling framework. These environments employed a combination of TE prototypes and software-based emulators for selected components, enabling a comprehensive test campaign without the limitations or hazards of a live railway infrastructure and train asset. The work builds on previous subsystem-level validation and focuses on the integration of interfaces, data exchanges, functional alignment and timing behaviours. A key element of the methodology was the use of the DATO prototype and the TMS emulation suite, which made it possible to observe system behaviour across a wide spectrum of operational conditions, including nominal service, degraded or fallback modes, and remote supervision situations.

The results of the test campaign confirm that the integrated GoA4 subsystem behaves consistently with the expected functional and interface specifications under laboratory conditions. The connections between the on-board subsystem, the TCMS and the emulated signalling architecture proved stable and reliable, enabling structured and repeatable test sequences. The DATO prototype provided valuable insights into the autonomous logic and its interaction with the broader control system, allowing to analyse decision-making mechanisms, state transitions and system responses in both regular and abnormal operational scenarios. The outputs of the laboratory tests include complete configuration settings, test plans, executed procedures and formal test reports, providing a traceable set of evidence that documents the maturity level achieved so far. The results provide a solid foundation for moving toward field integration and demonstrate readiness for the next waves of the project.

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ABBREVIATIONS AND ACRONYMS

ADM	Automatic Driving Module
AD	Automatic Driving
AF	Automating Functions
APM	Automatic Processing Module
ATO	Automatic Train Operation
ATO up to GoA4	System including Automating Functions, ATO technology, Perception
ATP	Automatic Train Protection (ETCS-OB)
DATO	Digital Automatic Train Operation
DMI	Driver Machine Interface
ERTMS	European Rail Traffic Management System
ERJU	Europe's Rail Joint Undertaking
ETCS	European Train Control System
GoA	Grade of Automation
HIL	Hardware In the Loop unit
HMU	Hybrid Multiple Unit
PER	Perception
R2DATO	Rail to Digital automated up to Autonomous Train Operation
RC-OB	Remote Control On Board
REP	Repository
RD	Remote Driving
RDS	Remote Driving System
TCMS	Train Control and Monitoring System
TE	Technical Enabler
TMS	Traffic Management System
TRL	Technology Readiness Level

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2 INTRODUCTION

The present document constitutes deliverable D39.7 "*Integration Activities Report*", produced within Work Package 39 (WP39) of the FP2 – R2DATO program under Europe's Rail Joint Undertaking (ERJU). WP39 focuses on the development, integration and validation of the autonomous on-board functions up to Grade of Automation 4 (GoA4) and Remote Driving, contributing directly to the objectives of Flagship Area 2 (FA2), particularly the activities related to the development of advanced Technical Enablers (TEs) for autonomous train operation. Within this framework, the T39.2 "*Laboratory Activities*", led by HITACHI with the participation of FSI, ProRail and Trafikverket, concentrates on the integration and early-stage verification of the GoA4 and Remote Driving systems in integrated laboratory environments. The work documented in this deliverable represents a key contribution to the progressive increase of the system's Technology Readiness Level (TRL), which advances from subsystem verification (TRL 4/5) to integrated laboratory validation (TRL 5/6). The contribution of this deliverable is twofold. On one hand, it supports the consolidation of the integration activities related to multiple TEs in FP2 R2DATO, such as the GoA4 on-board subsystem, the Remote Driving System (RDS), the communication interfaces with the TCMS, and the interaction layer with the traditional signalling system. On the other hand, it provides the complete set of evidence associated with the laboratory-based integration of the demonstrators, complementing and extending the work reported in previous deliverables that addressed subsystem design and functional requirements (i.e., WP6, WP9, WP10, WP11 and WP12) and preliminary verification activities. D39.7 therefore serves as the bridge between the design-oriented phases of the project and the subsequent field-level demonstrations addressed in other WP39's tasks and related deliverables.

From a background perspective, GoA4 and Remote Driving operations in mainline railways remains a major technical and operational challenge. While metro-like environments have already demonstrated mature automation capabilities, their operational constraints and system architectures are not directly transferable to interoperable European rail networks, where heterogeneous signalling, mixed traffic, and safety-critical requirements impose a fundamentally different integration context. Previous work within R2DATO - including modelling activities, subsystem-level prototyping, and interface specification - laid an essential foundation by defining the functional building blocks necessary for autonomous operation and by validating early versions of the TEs. Following this documental baseline (see reference [1]), full integration of the GoA4 and Remote Driving related subsystems with the TCMS and signalling architecture had been demonstrated in a coherent and repeatable setup. This deliverable addresses precisely this phase by providing a complete validation of the integrated GoA4 and Remote Driving chain in laboratory conditions representative of the demonstrator context.

The motivation for the laboratory phase is rooted in the need to reduce risk and ensure system stability before any field deployment, but also in the awareness that key WP39 demonstration assets—namely the test train and the San Donato test ring—were available to the project for a limited time window (only 5 weeks). In this context, anticipating and consolidating as much integration and validation activity as possible in laboratory environments was a fundamental prerequisite to maximise the effective use of these assets during the field phase. The interaction between autonomous driving, TCMS functions, and signalling constraints involves complex timing behaviour, mode transitions, fallback strategies and real-time data exchanges, all of which must be thoroughly analysed in a configurable environment. The laboratory setups described in this deliverable enable this analysis by combining TE prototypes with software-based substitutes for signalling components,

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which allows to reproduce nominal and degraded scenarios, assess system response, and iteratively refine configurations and interfaces.

The primary objective of this deliverable is therefore to document the integration and validation activities conducted in these laboratory environments, explaining the technical rationale behind the integration strategy, the scenarios executed, the verification logic adopted, and the results achieved by the integrated system. It provides evidence of the interaction between the GoA4 and Remote Driving on-board subsystems, the Blues Train TCMS and the ETCS-based signalling architecture, demonstrating readiness for the transition to field testing.

Finally, this document is structured as follows:

- **Chapter 2** introduces the objectives, context and relevance of the work within ERJU and WP39.

- **Chapter 3** describes the integration environments that host the laboratory activities, including an overview of their architecture, components and purpose.

- **Chapter 4** presents the integration and validation approach, the scenarios executed and the strategy used to verify system behaviour.

- **Chapter 5** details the test plans, the corresponding execution and the resulting test reports produced during the campaign.

- **Chapter 6** summarises the conclusions, key findings and evidence supporting the system's integration maturity.

Overall, D39.7 provides a comprehensive and traceable summary of the work performed, highlighting the project's contribution to the development of GoA4 and Remote Driving operations and setting the basis for the next steps toward field-level demonstrations.

3 INTEGRATION ENVIRONMENTS

This chapter describes the laboratory integration environments established within Task 39.2 to support the progressive integration and validation of the GoA4 demonstrator prior to field deployment. Beyond their architectural composition, these environments are specialised to replicate, as closely as possible, the operational context of the final demonstrator, namely the San Donato test ring and the Blues train. To this end, the track-related data used within the environments are aligned with the specific characteristics of the San Donato infrastructure, including representative track layouts, gradients and topological features, while the train-related models reflect the dynamic behaviour of the Blues train, with particular regard to traction and braking performance. This approach ensures that the scenarios executed during laboratory integration are not only functionally representative, but also grounded in the real operational conditions foreseen for the field demonstration.

The AlphaTrain TCMS-oriented integration environment represents the first laboratory-level validation step where ATO and Remote Driving functions are exercised against a real train-level control and monitoring system. As such, it plays a key role in identifying potential integration issues at the vehicle interface level at an early stage, prior to system-level integration and on-track validation activities.

As introduced in Chapter 1, laboratory activities represent a fundamental step to consolidate the interaction between autonomous on-board functions, signalling systems and train-level subsystems in a controlled, repeatable and configurable context.

The integration environments presented in this chapter are described at a functional and conceptual level. For detailed information on the architecture of the integration laboratories, interface definitions, simulation tool capabilities, and the format of test scripts, reference shall be made to deliverable D39.5 "*Architecture and interfaces of the Integration Laboratories, tool capabilities, format of test script*" [2]. The present chapter builds on the reference material provided in D39.5 and focuses on the role, scope and usage of each environment within the integration and validation campaign reported in the next sections.

In line with the objectives of WP39, two main laboratory integration frameworks have been defined:

- a signalling-oriented integration framework, aimed at validating the interaction between the GoA4 and Remote Driving functions and the ATP/signalling domain. This integration environment consolidates all laboratory activities related to signalling, ATP and remote driving interaction, covering multiple operational configurations with increasing realism;
- a TCMS-oriented integration framework, aimed at validating the interaction between the GoA4 functions, the Remote Driving system and the TCMS system. This environment addresses laboratory integration with the real TCMS of the Blues train, enabling validation of train-level interaction.

To this end, four complementary integration environments have been produced:

- three environments named *ENV1*, *ENV2* and *ENV3*, addressing integration within the signalling framework under different levels of realism and components substitution.
- One environment named *AlphaTrain*, addressing integration of GoA4 and RDS technologies with the real TCMS of the Blues train.

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Together, these environments provide a coherent integration chain that enables early functional verification, interface validation, and behavioural testing of the GoA4 and Remote Driving systems in both nominal and degraded operational scenarios, thereby supporting the incremental increase of the overall system TRL.

3.1 SIGNALLING INTEGRATION LABORATORY ENVIRONMENT

3.1.1 Scope and Functional Objectives

The primary objective of the Signalling Integration Laboratory Environment is to validate the correct interactions among the core GoA4 functional components (namely ADM, APM and REP) and the RDS with the signalling/ATP domain.

Across its operational configurations, the environment enables verification of the system's capability to:

- execute basic mission profile tasks in nominal conditions;
- handle degraded operational scenarios (e.g. communication loss, mission interruption and restarting situations);
- manage safe transitions between autonomous operation and remote controlling.
- operate in GoA up to 4 and in Remote driving under representative ATP constraints, including movement authorities and speed supervision.

3.1.2 Integration Architecture and Operational Configurations

The environment is built around a modular architecture in which real target components are progressively integrated with simulation tools, as reported in [2]. The following operational configurations are supported:

- **GoA4 On-Board Integration with Emulated Signalling – *ENV1***

  In this configuration, ADM, APM and REP are deployed on the target hardware platform, while all external subsystems and signalling elements are emulated using the *SimATO* tool. This configuration enables early end-to-end integration testing of GoA4 components, focusing on interface correctness, data exchange and internal functional consistency.

- **GoA4 On-Board Integration with real ATP – *ENV2***

  To enhance operational realism, the real ATP (ETCS-OB) software is executed on a dedicated Thanos Host. More specifically, in this setup the Hitachi Thanos platform provides the hosting environment while running the unchanged ATP software, reproducing its actual operational logic, including movement authorities, speed limits, and supervision constraints. *SimATO* continues to emulate the remaining external subsystems and acts as an integration hub. This configuration enables validation of GoA4 behaviour under realistic signalling constraints while maintaining full controllability of the test environment.

- **Remote Driving Integration within the Signalling Framework – *ENV3***

  In an alternative configuration, the environment supports also integration of the Remote Driving System with the signalling domain. The Remote Driving desk is connected to the ATP provided by Thanos host, including the DMI, via dedicated communication modems. This configuration enables validation of the complete communication chain and functional correctness of ATP information as displayed and handled by the remote operator.

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Although these configurations differ in scope and realism, they are considered part of a single signalling-oriented laboratory environment, as they share common tools, interfaces, architectural principles and validation objectives.

3.2 TCMS-ORIENTED INTEGRATION ENVIRONMENT: ALPHATRAIN

While the Signalling Integration Laboratory Environment focuses on signalling and ATP interaction, the *AlphaTrain* environment addresses integration with the real Train Control and Monitoring System (TCMS) of the Blues Train.

The *AlphaTrain* environment has been specifically defined to validate the interaction among:

- the RDS,
- the GoA4 functional components (ADM, APM and REP),
- the real TCMS.

Within this environment:

- ADM, APM and REP are implemented in software-in-the-loop using the *SimATO* tool;
- *SimATO* receives real-time operational and vehicle data from the real TCMS through a Ethernet interface;
- communication between the RDS and the train is established via a wireless modem and the Remote Control On-Board (RC-OB) subsystem.

The AlphaTrain environment enables validation of:

- command transmission from the Remote Driving System, APM and ADM to train-level systems;
- correctness and timeliness of feedback from the TCMS;
- safe and consistent interaction between remote operation functions and vehicle control logic.

Note that although REP does not directly interface with the TCMS, it is included to preserve architectural consistency of the GoA4 system.

The TCMS integration environment is based on a mixed configuration combining real and simulated components, enabling realistic validation while maintaining laboratory controllability.

The environment comprises the following main elements:

- Real TCMS (MASACCIO HMU)

  The TCMS represents the real train-level control and monitoring system, including vehicle supervision and command execution logic.

- ATO subsystems

  The ATO functionality is implemented through the *SimATO* tool, which hosts the simulated ATO logics and interfaces toward TCMS.

- TCMS Hardware-In-the-Loop (HIL) unit

It simulates train subsystems interfacing with the TCMS (e.g. traction, braking and auxiliary equipment), allowing controlled stimulation of TCMS behaviour.

- Communication infrastructure

  Communication between TCMS, ATO and RDS is realized via Ethernet-based networks, according to predefined IP addressing and multicast group configurations.

The system architecture implemented in this environment corresponds to the configuration illustrated in [2].

The TCMS integration environment supports validation activities for both RDS and GoA up to 4 operation, using the same architectural setup while varying test scenarios and operational conditions.

In particular, the environment enables validation of:

- GoA2 ATO operation, including:
  - ATO enablement and activation;
  - execution of predefined operational scenarios;
  - transitions between automatic and manual driving;
  - handling of driver interventions and traction cut-off conditions.
- GoA4 ATO operation, including:
  - ATO operation with virtual driving desk enabled;
  - automatic traction and braking commands generated by ATO;
  - interaction with TCMS during Parking, power-up and power-down sequences;
  - execution of ATO-initiated commands to train subsystems (e.g. doors, horn, direction control).
- Remote driving operation, including:
  - RD operation with remote driving desk enabled;
  - automatic traction and braking commands generated by RDS;
  - interaction with TCMS during Parking, power-up and power-down sequences;
  - execution of RDS-initiated commands to train subsystems (e.g. doors, horn, direction control).

4 INTEGRATION AND VALIDATION APPROACH

All integration environments described in this chapter are based on a shared set of principles:

- progressive replacement of real subsystems with software-based simulators or emulators to reduce integration risk;
- use of real target hardware for selected components once interface stability has been confirmed;
- execution of representative operational scenarios, including degraded conditions such as loss of communication, mission interruption and remote control takeover;
- reuse of common tools and interfaces where possible, ensuring traceability and consistency across environments.

Within the overall integration strategy, the TCMS-oriented environment complements the signalling-oriented integration laboratories by focusing on the interaction with real vehicle control logic, thereby contributing to the overall readiness assessment of the GoA4 demonstrator.

A key enabling element is the extensive use of simulation platforms, which allows real signalling components (e.g. ATP) and train functions to be substituted by software components running on host platforms, while preserving functional behaviour and interface semantics.

4.1 DESCRIPTION OF SCENARIOS

Building on the common integration principles outlined above, validation activities for the system integration tests have been structured around a scenario-based approach ensuring a comprehensive verification of functional behaviour as well as a structured, traceable, and comprehensive verification of system functionalities across different operational modes and operating conditions.

Within this framework, the validation campaign is centred on a set of representative operational scenarios derived from the reference document D39.3 (see reference [4]), which constitutes the reference baseline for the definition of operational behaviours and system use cases. These scenarios have been selected to cover the most significant operational contexts of the system, including nominal operations, mode transitions, and degraded conditions. In particular, they are designed to represent the system capability to cope with infrastructure bottleneck situations, such as operations in the presence of complex junctions or constrained network nodes, which may occur across different operational contexts (e.g. passenger, freight, or mixed-traffic operations), where traffic density, routing constraints, and control handovers impose additional operational challenges.

Scenarios execution within the integration environments ensures that system behaviour is assessed in situations that are both realistic and representative of real operational use. On the basis of this document, a set of five representative scenarios has been identified:

- The first scenario focuses on Remote Driving operations in shunting mode, with the objective of validating the correct execution of commands, system responsiveness, and control logic when the train is operated remotely in a controlled manoeuvring context. This scenario represents a fundamental use case and serves as an initial validation step within the progressive integration strategy. For ENV1 the operations in Remote Driving in this test are executed in GoA1.

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- The second scenario addresses the integration from Remote Driving operation to GoA4 movement, considering different intermediate stops and the management of the End of Train Service. This scenario has been defined to verify the seamless transition between Remote Driving and fully automated operation, ensuring that all required conditions are satisfied and that no unsafe or unexpected behaviours occur during the transition phase. For ENV1 the operations in Remote Driving in this test are executed in GoA1.
- The third scenario covers the transition from GoA4 operation back to Remote Driving. This reverse integration path has been defined to assess the system's capability to correctly manage the handover of control authority, guaranteeing continuity of operation and consistency of system states throughout the transition. For ENV1 the operations in Remote Driving in this test are executed in GoA1.
- The fourth scenario concerns GoA4 movement in the presence of an obstacle on the line. This scenario is particularly relevant for the assessment of system robustness and safety-related reactions. In addition to the nominal condition, several degraded sub-scenarios are included in order to evaluate the system robustness and safety responses under abnormal or fault conditions. These include:
    - reaction to the failure of a system component (PER failure);
    - loss of Automatic Driving (AD) mode reported by ATP;
    - loss of operational conditions caused by a delayed Journey Profile update;
    - reaction to the transition of ATP into TRIP mode.
- The fifth scenario addresses the integration between GoA2 and GoA4 operations, ensuring that transitions between different Grades of Automation are correctly managed. This scenario validates interoperability between automation modes and confirms that the system behaves consistently with its functional and operational requirements during such transitions.

4.2 VALIDATION STRATEGY

The validation strategy associated with these scenarios is based on a structured and traceable test definition process. Starting from the functional descriptions and use cases contained in document D39.3 ([4]), the corresponding tests have been developed and collected within a dedicated Test Suite, implemented in Excel format. The Test Suite represents a central artefact of the validation process, as it provides a comprehensive definition of each test case, including inputs, and expected outputs.

Test inputs are defined as the set of conditions or stimuli required to trigger the system behaviour under verification; those represent either operational conditions naturally occurring during system operation, such as the reaching of specific metrics or states, or deliberate stimuli injected by the tester. The latter are particularly relevant for the validation of degraded scenarios, where specific variables are forced or manipulated in order to evaluate system behaviour under degraded or abnormal conditions.

Test outputs correspond to the system responses to the applied inputs. During test execution, these outputs are directly monitored by the tester. Where a deeper analysis is required, system logs generated during execution are analysed in order to verify internal system behaviour, to support the interpretation of test results and to confirm compliance with expected results.

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The overall validation process is therefore composed of the following main steps:

- Definition of test cases on the basis of the scenarios described in document D39.3;
- Creation of tests in a format compatible with the integration and test environment in use;
- Execution of the tests in the defined integration test environment;
- Analysis and assessment of test results.

This approach ensures consistency, traceability, and completeness across the integration and validation activities, in alignment with the principles and objectives defined at the beginning of this chapter.

The results obtained from the validation activities performed in the TCMS-oriented integration environment provide objective evidence of functional correctness, operational consistency across automation levels, and system maturity, supporting the transition towards higher-level integration phases and field demonstrations.

5 TEST PLANS AND TEST RESULTS

It should be noted that the testing activities presented in this deliverable are primarily aimed at integration verification and functional validation of interfaces. They are not intended to provide a complete assessment of system performance or operational KPIs, which will be addressed in subsequent phases of the project under real operational conditions.

5.1 TEST PLAN FOR SIGNALLING INTEGRATION LABORATORY

5.1.1 ENV1

This Test Plan defines the scope, objectives, test strategy, environment configuration, execution approach, and acceptance criteria for the integration testing activities carried out in the ENV1 environment.

The purpose of ENV1 testing is to validate the correct functional and interface-level integration among the core GoA4 onboard components developed within WP39, prior to the progressive introduction of real external subsystems in higher-level integration environments.

The primary objective of ENV1 is to validate the interaction among the following GoA4 functional components, all deployed as real target components:

- Automatic Driving Module (ADM)
- Automatic Processing Module (APM)
- Repository (REP)

In the ENV1 environment, all external signalling subsystems are emulated through the SimATO simulator.

SimATO provides a comprehensive simulation framework capable of reproducing the behaviour of signalling-related devices and subsystems external to the GoA4 onboard system. This configuration allows the core components under test to operate in a controlled yet representative environment, enabling early verification without the added complexity and risk associated with the integration of real external subsystems.

Included in scope:

- Interface validation between ADM, APM and REP
- Correct data exchange among GoA4 components
- Functional behaviour of GoA4 components according to defined operational scenarios
- Validation of nominal and degraded operational flows

Out of scope:

- Integration with real external signalling subsystems

The ENV1 test scenarios are derived from the five operational scenarios defined in the reference document D39.3 (§4.1), which specifies system functionalities and use cases.

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Each scenario described in D39.3 is characterised by a specific Mission, which is further decomposed into one or more Journeys. Each Journey represents a coherent operational sequence that can be independently executed and verified. This structure supports a modular, traceable, and systematic testing approach.

Within D39.3, scenarios are further structured into Use Cases, grouped into fifteen tables according to the macro-functionalities to be achieved. These tables define the functional expectations that must be satisfied in order to consider a given functionality successfully completed, and they constitute the reference baseline for test expectations and acceptance criteria.

The assessment focuses on verifying that all functionalities defined in D39.3 are correctly implemented and executed by the system. The evaluation is performed using the use case tables in D39.3 as objective acceptance criteria.

Entry Criteria

- Test environment correctly configured
- Software versions formally released
- Test scenarios validated and available

Exit Criteria

- All planned test cases executed
- Logs analysed
- No open blocking issues

Test Tools

- SimATO – simulation and test automation
- LogExplorer – log analysis and reporting

5.1.2 ENV2

This Test Plan defines the scope, objectives, test strategy, environment configuration, execution procedures, and acceptance criteria for the integration testing activities performed in the ENV2 environment.

The purpose of these tests is to validate the correct functional and interface-level integration between:

- the developed ATO up to GoA4 onboard subsystems (ADM, APM, REP) and
- the ATP system (simulated by Thanos), and

prior to deployment in demonstrators and operational validation phases.

ENV2 is intended to validate the integration between the onboard ATO components and an ATP system under realistic operational conditions.

Included in scope:

- Data exchange between ADM, APM, REP and ATP
- Functional consistency and timing of interfaces

- Nominal operational scenarios

Out of scope:

- ATP functional safety validation
- Line-level performance and radio stress testing

For this environment, second and fourth scenarios have been planned and tested (see §4.1).

Entry Criteria

- Test environment correctly configured
- Software versions formally released
- Test scenarios validated and available

Exit Criteria

- All planned test cases executed
- Logs analysed
- No open blocking issues

Test Tools

- SimATO – simulation and test automation
- Thanos – ATP simulation environment
- LogExplorer – log analysis and reporting

5.1.3 ENV3

This Test Plan defines the scope, objectives, test strategy, environment configuration, execution procedures, and acceptance criteria for the integration testing activities performed in the ENV3 environment.

The purpose of these tests is to validate the correct functional and interface-level integration between:

- the developed ATO up to GoA4 onboard subsystems (ADM, APM, REP),
- the ATP system (simulated by Thanos), and
- the Remote Driving System.

prior to deployment in demonstrators and operational validation phases.

Included in scope:

- Correct reception and interpretation of ATP data by the Remote Driving Desk
- Accurate visualization on the Remote DMI
- Communication integrity between Remote Driving System and ATP
- Handling of nominal conditions

Out of scope:

- Human factors evaluation

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- Cybersecurity assessment

For this environment, first scenario has been planned and tested (see §4.1).

Entry Criteria

- Test environment correctly configured
- Software versions formally released
- Test scenarios validated and available

Exit Criteria

- All planned test cases executed
- Logs analysed
- No open blocking issues

Test Tools

- SimATO – simulation and test automation
- Thanos – ATP simulation environment
- LogExplorer – log analysis and reporting

5.2 Test Results For Signalling Integration Laboratory

5.2.1 ENV1

All tests have been successfully executed and thoroughly analysed, confirming that the prototype is sufficiently mature to be used on the field for the San Donato Test Ring demonstration, as per Integration Validation Test Report [5].

5.2.2 ENV2

Following table shows test results.

Test Cases Executed	Passed	Not passed
2	2	0

Results Overview

- All scenarios: PASS
- No packet loss detected
- Correct timing and consistency of ATP data exchange

Main Findings

- Stable synchronization between ATO components and ATP
- Proper handling of operational conditions

Issues

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- No high-severity issues identified

5.2.3 ENV3

Folllowing table shows test results.

Test Cases Executed	Passed	Not passed
1	1	0

Table 1: Test result performed in ENV3

Results Overview

- All scenarios: PASS
- No packet loss detected
- Correct timing and consistency of ATP and Remote Driving data exchange

Main Findings

- Accurate visualization of ATP data on Remote DMI
- Correct functional behaviour of the Remote Driving Desk
- Minor timing degradation under abnormal network conditions
- Proper handling of operational conditions

Issues

- No high-severity issues identified

5.3 TEST PLAN FOR TCMS-ORIENTED INTEGRATION ENVIRONMENT

This Test Plan defines the scope, objectives, test strategy, environment configuration, execution procedures, and acceptance criteria for the integration testing activities performed in the TCMS integration laboratory (ALPHA TRAIN).

The purpose of these tests is to validate the correct functional and interface-level integration between:

- the developed ATO up to GoA4 onboard subsystems (ADM, APM, REP),
- the Remote Driving System, and
- the TCMS system (real device on target platform).

prior to deployment in demonstrators and operational validation phases.

These integration tests are not limited to the execution of individual functional checks, but aim at providing the first train-level laboratory validation of the interaction between ATO (up to GoA4), Remote Driving functions and a real TCMS.

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In particular, the objective of the TCMS integration test campaign is to verify the functional continuity and consistency of system behaviour across different Grades of Automation, ensuring a coherent transition from legacy GoA2 operation to advanced GoA4 autonomous operation.

Included in scope:

- Correct data reception/transmission and interpretation between TCMS and ATO up to GoA4
- Correct data reception/transmission and interpretation between TCMS and Remote Driving System

Entry Criteria

- Test environment correctly configured
- Software versions formally released
- Test scenarios validated and available

Exit Criteria

- All planned test cases executed
- Logs analysed
- No open blocking issues

Test Tools

- SimATO – simulation and test automation
- ALPHA Train – TCMS testing environment
- LogExplorer – log analysis and reporting

Test execution follows a procedure-driven approach, where each test case is defined in terms of initial conditions, actions, expected data exchanges and acceptance criteria, derived from the applicable Functional Test Procedures for TCMS–ATO integration.

The validation strategy focuses on the verification of data exchanges and operational state transitions between ATO, Remote Driving System and TCMS. Primary validation evidence is represented by the analysis of dataset values and system state changes, ensuring consistency between commanded actions and TCMS-reported status throughout all test scenarios.

For this environment, first and second scenarios have been planned and tested (see §4.1).

Test Identifier	Action	Check
GOA4_AD_TST_01	Set direction to FORWARD. Switch driving mode selector to ATO.	ATO mode active.

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GOA4_AD _TST_02	Set direction to FORWARD. Press ATO button on DMI.	Train moves under ATO control.
GOA4_AD _TST_03	Set direction to FORWARD. Press ATO button. After stop, press ATO again.	ATO drives train, switches to manual at stop, then re-engages ATO and restarts automatically. Ds12411 B4 transitions correctly during journey.
GOA4_AD _TST_04	Start ATO driving. During traction, apply service braking 10%. After stop, reselect ATO and restart. Apply full traction while ATO active.	ATO disengages on braking, manual mode active. ATO re-enabled correctly. Ds12001 bytes reflect braking, stop, restart. ATO remains active despite manual traction input.
GOA4_AD _TST_05	Start ATO driving. Simulate train traction cut-off during motion.	ATO disengages. Traction effort drops to zero.
GOA4_AF _TST_01	Perform Parking entry operations. Set driving mode selector to ATO. Enable virtual desk.	ATO enabled, train exits Parking. Coherent indication of ATO state and active virtual desk.
GOA4_AF _TST_02	Allow ATO to manage braking, traction, and station stop. Remove traction cut-off causes if present.	Train fully driven by ATO.
GOA4_AF _TST_03	ATO commands door release, door closing, horn ON/OFF, Parking entry, and train shutdown.	All commands executed correctly. Ds12001 Byte52 updates per command. Ds12411 counters increment. Train enters Parking and safely powers off.

Table 2: ATO up to GoA4 Test plan. AD stands for Automatic Driving while AF stands for Automating Functions.

Test Identifier	Action	Check
RD_TST_01	Connect PC Host to Alpha Train	Check the connection is OK (all cables shall be properly connected)
RD_TST_02	Activate the AlphaTrain, RC-OB, Sniffer and TCMS Converter on PC Host	Check the tools are properly running Check the communication between AlphaTrain and Tools is OK

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		Check the remote connection between RC-OB and Remote Driving Desk Controller is OK
RD_TST_03	Open Remote Desk and start to drive the train, reaching a speed of 30 Km/h	Check the AlphaTrain correctly receives traction/coasting commands from Remote Desk and manages them Check the Remote Desk correctly receives and manages data from AlphaTrain
RD_TST_04	Brake reaching a speed of 0 Km/h	Check the AlphaTrain correctly receives braking commands from Remote Desk and manages them Check the Remote Desk correctly receives and manages data from AlphaTrain
RD_TST_05	Close Remote Desk, applying Parking Brake	Check the AlphaTrain correctly receives and manage data, considering the Remote Desk as closed and parking brake applied Check the Remote Desk correctly receives and manages data from AlphaTrain

Table 3: Remote Driving System Test plan

Successful completion of the TCMS integration tests provides objective evidence of system integration maturity and constitutes a prerequisite for subsequent higher-level system validation activities and field demonstrations.

5.4 TEST RESULTS FOR TCMS-ORIENTED INTEGRATION ENVIRONMENT

Following table shows test results.

Test Cases Executed	Passed	Not passed
13	13	0

Table 4: Test result performed in in the TCMS integration laboratory (ALPHA TRAIN).

Results Overview

- All scenarios: PASS

- Correct execution of all ATO GoA4 and Remote Driving test cases.
- Correct data exchange and state transitions between ATO, RDS and TCMS
- No communication losses, inconsistencies or unexpected behaviours detected

Main Findings

- Correct interpretation and execution of ATO commands by the TCMS
- Proper handling of ATO engagement, disengagement and mode transitions
- Correct management of traction, braking, Parking and power-up/power-down sequences
- Correct execution of ATO-initiated functions (doors, horn, direction control)
- Stable and consistent interaction between Remote Driving System and TCMS

Issues

- No high-severity issues identified

6 CONCLUSIONS

The work carried out in the framework of Deliverable *D39.7 – Integration Activities Report* has achieved its primary objective: demonstrating that the GoA4 on-board subsystem, the Blues Train TCMS and the signalling architecture can be successfully integrated and validated in controlled laboratory environments representative of the demonstrator. By establishing two dedicated integration setups, configuring the relevant TEs, and executing structured test campaigns, the functional alignment, interface consistency and overall readiness of the integrated system for progression to field-level validation have been confirmed. These results mark a significant advancement in the maturity of the autonomous train operation chain within FP2 – R2DATO, contributing to the continual increase of the system TRL.

Beyond the technical validation results, an important outcome of the reported activities is the significant anticipation of integration work with respect to the field phase. The laboratory-based approach made it possible to consolidate the majority of integration and verification activities prior to on-track deployment, thereby reducing to a minimum the integration effort required on the real train and infrastructure. This strategy allows the effective use of the available demonstration assets to be focused primarily on functional testing, demonstrative activities and dissemination, maximising their value within the limited time window foreseen for field operations.

The activities performed provide new knowledge that goes beyond the earlier subsystem-level developments reported in previous deliverables. The laboratory phase enabled the first comprehensiveobservation of system behaviours emerging from the interaction of behaviourautonomous logic, TCMS functions and signalling substitutes under nominal, degraded and remotely supervised scenarios. The use of the DATO prototype and the TMS emulation suite proved essential in gaining insights into transition logic, timing interactions, fallback handling and overall system robustness. The outputs of the test campaign (such as configuration settings, test plans and formal test reports) constitute a traceable evidence package that confirms the achieved integration behaviour and supports the next stages of the R2DATO demonstrator. As such, the work documented here represents an important contribution to the broader objectives of Europe’s Rail in enabling safe and interoperable GoA4 and Remote Driving operation on the mainline railway network.

Overall, the evaluation of the activities shows that the laboratory integration objectives have been successfully met. The system demonstrated stable and consistent performance, with the tested interfaces behaving in accordance with the defined specifications. At the same time, the campaign highlighted several challenges inherent to laboratory-based validation. Some signalling behaviours and dynamic train responses cannot be fully reproduced through software emulators, and certain timing-dependent interactions will require confirmation in a real-world environment. Managing the configuration alignment across multiple subsystems also proved demanding, emphasizing the importance of rigorous interface control and documentation practices. These limitations do not diminish the value of the work; rather, they provide clear guidance for subsequent phases and reinforce the need for a structured transition toward field demonstrations.

The work performed has produced several lessons learned. Notably, the early availability of emulation tools significantly reduces integration risks, allowing to test autonomous logic under controlled conditions before interacting with actual signalling equipment. The results also confirm the importance of progressive integration, where subsystem-level validation is followed by laboratory

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integration before entering the field. This staged approach aligns well with the Europe's Rail system architecture and supports the long-term objective of ensuring safe deployment of high-automation technologies.

Some open points remain, primarily related to the inherent limitations of laboratory setups. These include the need to validate certain timing-critical behaviours using real rolling stock, to confirm the system's response to environmental disturbances, and to assess the full interaction between autonomous functions and the operational ETCS infrastructure. These aspects will be addressed in the forthcoming field integration and demonstration activities planned in later waves of project.

Looking ahead, the results of D39.7 provide a strong foundation for the next phase of R2DATO. The validated integration configurations, the knowledge gained on interface behaviour and the evidence collected through laboratory tests will directly support the setup of the field demonstrator and the refinement of the autonomous logic in preparation for real-world operation. Continued work within Europe's Rail will be essential to complete the transition from laboratory validation to operational deployment, to further mature GoA4 and Remote Driving functionalities, and to contribute to future standardization, regulatory developments and market acceptance of autonomous train operation.

In conclusion, the work carried out under this deliverable demonstrates substantial progress toward the integration of GoA4 and RDS components, delivers valuable new insights on system behaviour and readiness, and establishes a solid and verifiable basis for the continuation of the demonstrator activities within the Europe's Rail program.

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