

The Latest Advancements in Fully Automated Train Operation Incorporating EU-RAIL Results in Czechia

Peter Gurnik^{1*}, Michal Matowicki¹ [0000-0002-2630-1704], Michal Novak¹, Petr Stríteský¹ [0009-0001-7323-5711], Quentin Baar², Gavino Brundu³, Francisco Parrilla Ayuso⁴

¹ AZD Praha s.r.o., Prague, Czechia

*gurnik.peter@azd.cz

matowicki.michal@azd.cz

novak.Michal2@azd.cz

stritesky.petr@azd.cz

² ALSTOM Belgium SA, Charleroi, Belgium

quentin.baar@alstomgroup.com

³ WABTEC (Faiveley Transport Italia S.p.A.), Piossasco, Italy

gavino.brundu@wabtec.com

⁴ INDRA SISTEMAS, S.A., Madrid, Spain

fparrilla@indra.es

Abstract. This paper presents the WP46 regional line demonstrator developed within the Europe's Rail R2DATO project. The work focuses on the validation of GoA3/GoA4 automation functions developed according to the R2DATO specifications and demonstrated on a fully operational regional railway line in Czechia while ensuring interoperability with ERTMS/ETCS. The paper describes the demonstrator architecture and the role of key technical enablers, including perception, absolute safe train positioning (ASTP), remote control, and automation decision-making modules. It also explains the traceability between ATO GoA3/GoA4 use cases and requirements and the scenario-based test programme prepared for the Kopydlno–Dolní Bousov line using the EDITA experimental vehicle. The proposed approach combines laboratory validation, system integration, and on-track testing to verify system behaviour under realistic operational conditions. Particular attention is given to interoperability and interchangeability of modules provided by multiple suppliers. The work provides a practical basis for the 2026 demonstration campaign and contributes feedback to the ongoing development of GoA3/GoA4 specifications.

Keywords: Autonomous Railway; GoA3/GoA4; Automatic Train Operation (ATO); ERTMS/ETCS; Perception; Absolute Safe Train Positioning (ASTP); Regional Line Demonstrator.

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1 Introduction

Railway automation is moving rapidly from incremental improvements to a transformative shift that may redefine how rail transport is organised and perceived. The transition to higher Grades of Automation (GoA) such as GoA3 and GoA4 represents a step-change. At GoA3, the driver is no longer required to operate the train, but an attendant is on board for emergencies, door operation and travellers' assistance. At GoA4, there is no human staff on board; trains operate fully automatically. The potential benefits are substantial: improved operational safety by removing human error, enhanced energy efficiency through optimized driving strategies, and increased track throughput due to precise timetable adherence.

At the same time, the complexity of implementing GoA3/4 should not be underestimated. Integration challenges include ensuring interoperability in line with safety systems (Interoperable automatic train protection system (ATP) – ETCS), managing degraded modes when automation fails, and integrating new subsystems such as perception, absolute safe train positioning (ASTP), and remote control (RC). Moreover, certification must account for new ways of developments and introducing the new functionalities and methods, raising the bar for validation and verification [1]. Recent scoping and architecture studies highlight that integrating train-driving automation with signalling constraints and multi-supplier interfaces remains a primary barrier to GoA3/4 deployment on mainline and regional networks [10,11].

Regional lines represent an ideal proving ground for automation technologies. Unlike metro lines, which operate in closed environments, regional railways are exposed to diverse real-world conditions: aging infrastructure, mixed freight and passenger traffic, non-separated rails (no physical barrier around track) and frequent unprotected level crossings. Demonstrating GoA3/4 in such contexts allows stakeholders to evaluate the feasibility of deploying automation at scale. The Czech regional line Kopidlno–Dolní Bousov (K-DB) has been selected for demonstrations within Work Package 46 (WP46) of Europe's Rail project R2DATO. It combines challenging conditions with the advantage of being under the direct management of R2DATO consortium member, enabling experimental access and operations.

WP46 aims to define test scenarios, plan demonstrations, and validate the technical enablers, tested on regional lines environment. The overall approach for demonstration is captured in R2DATO public deliverable D46.1 [6], which is a basis for this paper.

2 Background and Related Work

Automatic Train Operation (ATO) in rail has followed a gradual trajectory. GoA1 and GoA2 have already been widely deployed. Today, GoA2 for mainlines already exists as a fully interoperable solution—ERTMS ATO—comprehensively specified in the 2023 Technical Specification for Interoperability (TSI CCS [7,12]). These grades maintain a driver onboard, either for full control (GoA1) or supervision (GoA2). Progressing to GoA3 and GoA4 substitutes the driver completely, thus introducing new challenges in monitoring the space in front of the train, degraded mode management, situational awareness, decision making capabilities and even management of doors and other onboard functionalities.

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European research has been at the forefront of addressing these challenges. The EU funded SHIFT2RAIL X2RAIL [8] projects piloted early prototypes of GoA4 automation, demonstrating the feasibility of combining ETCS with automated driving. The projects also explored perception systems and on-board digital repositories. Another EU funded project TAURO [9] concentrated on perception and remote driving, developing further functional requirements and inputs that have been a valuable input source for R2DATO.

Despite progress, further development is still needed. R2DATO's WP46 addresses some of these developments by integrating and validating technologies in a coherent system on a regional line. Unlike earlier projects, WP46 introduces not on latest technology uptake but also planning demonstrations that bring together multiple partners, suppliers, modules and validate the interchangeability capabilities following the current status of R2DATO specifications.

For presented work, the ATO GoA3/4 System Requirements Specifications (SRS v1.1.0), released by R2DATO project [4], are treated as the sole authoritative source of requirements. All use cases and requirements selected for the demonstrator are derived from this specification to ensure full consistency with the official reference for European automation developments.

Due to ongoing work in R2DATO project, not all specifications are completely developed as of yet. In those cases where the SRS does not yet provide complete coverage for the targeted use cases, WP46 partners propose interim solutions. These are designed to resemble as closely as possible the directions expected in future SRS updates, ensuring progress without diverging from the SRS framework. This approach provides strong feedback for future specification work.

3 Methodology

WP46 employs a structured methodology linking system requirements to practical demonstrations. The methodology ensures that every test scenario corresponds to operational needs and provides feedback to specifications.

- Step 1. Identification of relevant Technical Enablers for demonstration – ADM, ASTP, PER and RC were selected as priorities.
- Step 2. Selection of Use Cases – More than 20 use cases were drawn from R2DATO deliverables, covering preparation, operation, events that may lead to safety-critical situations, and degraded modes.
- Step 3. Gap Analysis – The SRS v1.1.0 was reviewed against use cases. Gaps were identified in localisation and perception integration, requiring interim solutions
- Step 4. Development of Test Scenarios – Each use case was translated into a test scenario defining proper reactions of the system during tests and means of its verification.
- Step 5. Environment Characterisation – The K-DB line and EDITA vehicle were assessed. Constraints such as track access and optimal testing conditions were identified.
- Step 6. Planning and Integration – A Gantt chart defined milestones, including module delivery, integration, pilot tests, and final demonstrations.

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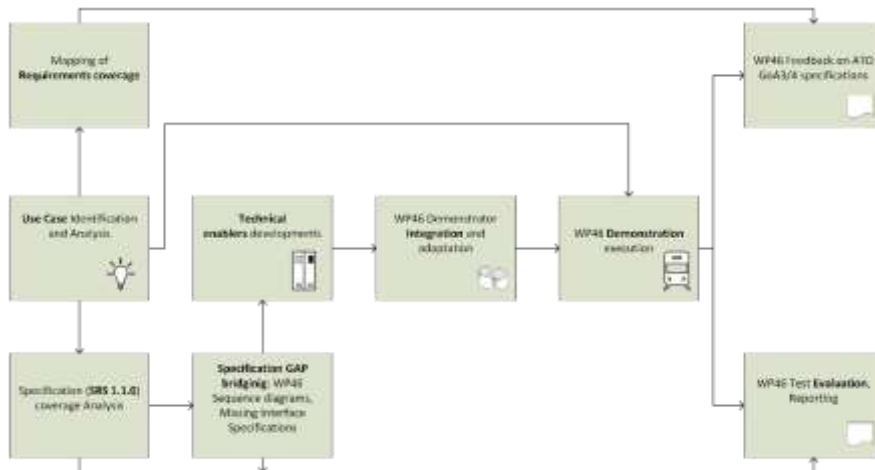


Fig. 1. Workflow and methodology of WP46 demonstrator

This process ensures traceability from high-level specifications to practical demonstrations, while also providing a feedback loop from demonstration to specification (See Figure 1).

4 Technical Enablers and Components

WP46 addresses five Technical Enablers (TEs) essential to GoA3/4: Automating Functions (AF), Automatic Driving Module (ADM), Absolute Safe Train Positioning (ASTP), Perception (PER), and Remote Control (RC). For each TE, WP46 focuses on interface compliance, functional performance, and evidence collection under realistic operational conditions, rather than supplier-specific implementations.

4.1 Automatic Driving Module, Automating Functions and Repository

The ADM extends the capabilities of GoA2 ATO to enable GoA3/4. Together with Automatic Processing Module (APM), it is responsible for executing train driving functions, from acceleration and braking to dwell time management at platforms and reaction to obstacles. The ADM must integrate with ETCS, TCMS (Train Control and Monitoring System), localisation systems, and perception. It must also manage degraded modes, handovers, and fallback procedures. Two ADM implementations are compliant with interface standards such as TSI CCS Subset-126, Subset -130, and Subset -139.

On top of the ADM and APM modules, the specified GoA3/4 architecture assumes presence of onboard Digital Repository (REP-OB), which provides a structured, digital representation of infrastructure and updated mission and operational data. It stores static and semi-static data such as gradients, speed restrictions, level crossing positions and timetables. Onboard systems retrieve this information for planning and execution.

WP46 tests focus on verifying consistency, ensuring that REP-OB modules from different suppliers can interoperate. In the demonstrator, REP-OB is treated as a replaceable module; test cases validate consistency of map/mission data and timing across suppliers to support interchangeability.

4.2 Absolute Safe Train Positioning

ETCS localisation is primarily based on odometry and balise information, which may not be sufficient for GoA3/4. ASTP provides continuous, safe localisation using GNSS, inertial measurement, and data fusion. Its role is to supply absolute position, speed, and orientation with the required reliability level. In WP46, ASTP will be integrated, ensuring that position information is consistently available to onboard modules.

4.3 Perception

Perception systems equip trains with situational awareness akin to human vision. Cameras with various focal points, LiDARs, infrared sensors and others enable detection of obstacles, recognition of signals, and evaluation of track conditions. Related use cases include detecting road vehicles at unprotected crossings, recognising livestock near tracks, and adapting to low-visibility conditions. In WP46, perception systems developed by AŽD and WABTEC will be installed on the EDITA vehicle.

4.4 Remote Control

RC provides the ability to operate trains remotely, either as a degraded mode fallback or for specific operations such as shunting. It requires reliable communication, low latency, and a human-machine interface that enables remote drivers to monitor and intervene. WP46 will test scenarios where RC is used for normal operations, degraded fallback, and transitions between local and remote control.

5 Testing Environment

The testing environment combines the K-DB line and the EDITA vehicle. The KD-B line is a regional railway line between Kopidlno and Dolní Bousov in the Czech Republic, and it has been selected as the main demonstration environment for WP46. The line is around 20 km long and represents a typical secondary regional route with low traffic and mixed operating conditions. Its infrastructure underwent modern CCS upgrades, making it particularly suitable for testing advanced automation functions in realistic settings.

The line is equipped with ETCS Level 2, GSM-R, and a 5G connectivity, which allow for both standardised train protection and high-bandwidth experimental communications. Several unprotected level crossings are present along the route, offering natural scenarios for validating perception modules against road vehicle incursions or wandering animals.

EDITA Vehicle (see Figure 2), is a modified class 810 railcar renovated and modified solely for the purpose of testing fully automatic operations, serves as the demonstration platform. It is equipped with ETCS OBU, modern TCMS, and ATO GoA2 as baseline. External cabinets host prototypes of ADM, REP, and ASTP modules. Perception sensors are integrated directly to the vehicle on the roof and front. Antennas support GNSS, GSM-R, and 5G communication via flexible platform that allows to exchange antenna as needed. EDITA can operate as a single unit or with a wagon, enabling flexibility in testing different operational scenarios.



Fig. 2. Testing environment and testing vehicle of WP46 demonstrator

Since today's ETCS was not originally designed to handle functions like obstacle detection or automatic adaptation to conditions related with fully automatic operations, the Protection Adaptation Layer (PAL) is introduced as an interface between standard ETCS and onboard automation system (OAS). PAL takes the standard ETCS information and adapts or enriches it so that new GoA3/4 functions—such as reacting to obstacles, applying speed restrictions, or recognizing signals—can be supported without changing the existing ETCS core. In this way, PAL ensures that innovative automation features can be tested and demonstrated while still staying compatible with the standard ETCS framework.

6 Testing and Demonstrations

The validation of GoA3/4 specifications in WP46 is structured around a set of carefully defined test scenarios (TS). Each test scenario is directly derived from one or more operational use cases documented in R2DATO and mapped to requirements in the ATO GoA3/4 System Requirements Specification. By working in this structured manner, WP46 ensures that demonstrations are traceable to the official system architecture and specifications while also providing feedback to refine future specifications.

Every test scenario involves a selection of technical enablers and supporting infrastructure to validate:

- Driving functions, which process inputs from ETCS, PER, REP-OB, and ASTP, and translates them into traction and braking commands. Braking and acceleration commands issued by ADM at all times adhere with ETCS protection limits.

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- Perception capabilities, for detection of obstacles, animals, signals, or weather limitations through onboard sensors (cameras, LiDAR, radar). Test will prove the correct identification and transmission of obstacle detection alerts as well as correct system response (e.g., emergency braking).
- Positioning functions, which provides continuous localization data, ensuring that all the components needing accurate positional input can properly operate. At the same time, localisation data shall be consistent with digital infrastructure maps.
- Remote control functions are verified as the capability for supervision or direct control for specific operational scenarios. Testing is focused on ensuring that remote commands can override or complement ADM outputs in specific operational situations.

Each test scenario has specific objectives, which generally fall into four categories:

1. **Functional Verification:** To demonstrate that each TE performs its intended function according to SRS requirements. Example: Verification that that vehicle operates fully autonomously according to the steps specified in received Mission Profile.
2. **Safety relevant Behaviour:** To confirm that the system responds correctly to abnormal or dangerous conditions. Example: Validation that when PER detects an obstacle, ADM initiates braking and train safely stops within ETCS limits.
3. **Interoperability and Interchangeability:** To test whether modules from different suppliers can operate within the same system. Example: REP-OB from AŽD and Alstom must provide consistent outputs so that ADM can function regardless of supplier.
4. **Operational Feasibility:** To evaluate whether GoA3/4 concepts can be applied under real-life regional line conditions. Example: Test whether a remote driver can reliably operate a train via Remote Control.

Preparation of practical tests include the laboratory or bench testing phase. Each technical enabler is verified individually or in small clusters before being placed on the vehicle. This stage focuses on confirming that interfaces are correctly implemented and that data flows follow the SRS v1.1.0 requirements.

The integration phase brings these modules together on the EDITA experimental vehicle. Here, physical connections with the TCMS, ETCS OBU, and communication networks (GSM-R, 5G) are validated. This step ensures that components from different suppliers can coexist on a common platform. Careful monitoring is applied to data exchange and correct functional behaviour to verify that the vehicle operates consistently as a system.

Finally, in the on-site execution phase, the defined test scenarios are performed on the K-DB line. This exposes the integrated system to realistic operating conditions such as gradients, curves, unprotected level crossings, and weather influences. Scenarios cover both routine operations—such as platform stops—and safety-critical responses—such as obstacle detection or remote driving takeover. The objective is not only to demonstrate functionality but also to evaluate robustness, interchangeability of

components provided by different suppliers, and overall readiness for future GoA3/4 deployment.

7 Conclusion and Future Work

This paper presents the WP46 verification plan for demonstrating GoA3/4 automation capabilities on a regional line. By deploying the selected technical enablers, mapping demonstrator functions to R2DATO use cases and requirements, and translating them into executable test scenarios, the work establishes an evidence-oriented basis for field demonstrations. The K-DB line and EDITA vehicle provide a realistic environment for validating key capabilities, including automation decision making (ADM), absolute safe train positioning (ASTP), perception (PER), reporting to onboard (REP-OB), and remote control (RC).

The on-site campaign planned for early 2026 focused on multi-supplier integration, execution of the defined scenario set, and KPI-based analysis of functional and safety-relevant behaviour. Results will be used to refine Europe's Rail specifications and to support harmonisation of GoA3/4 concepts, bridging laboratory validation and scalable deployment on regional lines.

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