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Rail to Digital automated up to autonomous train operation

D39.3 – Demo specifications

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Interne

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EXECUTIVE SUMMARY

Within Work package WP39 – ATO over ERTMS demonstration on mainline, deliverable D39.3 belongs to Task 39.2: ATO over ERTMS demo in San Donato Test Ring.

The main objective of this deliverable is to describe the overall framework of tests, the basic architecture and the scenarios to be tested initially in lab and then on the test ring.

This demonstration will be performed using the newest generation hybrid train, named" Blues'' on RFI San Donato Test Ring.

ATO up to GoA4 and Remote Driving technologies will be deployed as described by the reference architecture defined in FP2-R2DATO.

This activity is meant to deliver a contribution to the research which bring a step forward with respect to what has been achieved in Shift2rail.

Therefore, the outcomes of Shift2Rail X2Rail-4 have been considered in development of the ATO GoA 3/4 test specifications.

Moreover, other relevant interfaces are those with the Flagship Projects FP1 MOTIONAL for rail traffic management systems and FP6 FUTURE for regional lines.

Continuous interactions are carried out with R2DATO WP2 – Technical Management and Coherence and, WP3 – Technical Engineering and Requirements Consistency, Demonstrators Cluster.

Finally, the relationship with the System Pillar is understood as fundamental and an exchange process and common activities are established to maximize efficiency and obtain joint results.

The exchanges with other activities are centred around the milestones defined in the FP2 work program: basically, the inputs from WP2, WP3, WP5, WP10 and System Pillar.

It should also be noted that what is described in this document is a snapshot at the date of submission and that over the life of the project these interrelationships may change. However, deliverable D39.3 represents an excellent starting point to establish a clear picture of each other's needs as well as a timeframe for the main exchanges and milestones.

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ABBREVIATIONS AND ACRONYMS

ACC-M	Computer Based Interlocking
ATO	Automatic Train Operation
ATO up to GoA4	System including Automatic Functions, ATO technology, Perception.
ADM	Automatic Driving Module
APM	Automatic Processing Module
BSC	Base Station Controller
BTS	Base Transceiver Station
EoJ	End Of Journey
EF	Exported Function
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GoA	Grade of Automation
HMI	Human Machine Interface
ISM	Incident Solving Manager
R2DATO	Rail to Digital automated up to autonomous train operation
RD	Remote Driver
PER	PERception
PIS	Passenger Information System
RBC	Radio Block Center
RCE	Event Recorder
REP	REPository
RC-OB	Remote Control On Board
RC-TS	Remote Control Track Side
RS	Rolling Stock
RUS	Railways Undertaking Supervisor
SoJ	Start of Journe
SSB	ETCS/STM On Board System
ST.P	Stopping Point
TClear	Task related to train CLearance from passengers
TCMS	Train Control Monitoring System

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TE1	Automatic function
TE4	ATO technology
TE6	Perception
TE7	Remote driving
TCG	Task Change GoA
TJP	Task related to Journey Profile
TM	Train Manager
TMS	Traffic Management System
TSI	Technical Specifications for Interoperability
TST	Task Set Train State

TABLE OF CONTENTS

Interne

LIST OF FIGURES

LIST OF TABLES

Interne

2 INTRODUCTION

WP39 demonstrator will realize in a relevant environment a set of automatic train operation technologies with the aim to verify the technology maturity level, overall performances improvements and migration strategies.

San Donato ring is the railway asset identified by RFI to host the field activities of the present work package. San Donato ring allows 16h/day tests (2 slots of 7h per day – 07h00-14h00 and 14h00-21h00 - working days), without interrupting ordinary commercial operation on the main network, supporting both new signalling (this line is already equipped with ERTMS - L2 with dedicated RBC), and rolling stock tests.

This demonstration will be performed using the newest generation hybrid train named “Blues” made available by Trenitalia, that can travel with diesel engines, on electrified lines and with batteries, allowing a 50% reduction in fuel consumption and CO2 emission compared to current diesel trains. This train will be equipped with the GoA4 components as described in the reference architecture defined in FP2-R2DATO (TE1, TE4, TE6, TE7).

In the first part of the present document is explained the realization of the integration between new technologies and the hosting railway system describing the solution to make the needed adaptation.

The second part is dedicated to the definition of test scenarios and the related functionalities covered by new systems. Here is also possible to understand the relevant advantages (capacity and punctuality) deriving from the synergy between digital automatic train operation up to GoA4 and the CCS evolution.

The tests will basically be focused on 2 main features:

- REMOTE DRIVING
- ATO OVER ERTMS WITH GOA4

Interne

3 DEMONSTRATOR DESCRIPTION

3.1 OPERATING ENVIRONMENT

3.1.1 San Donato Test Ring

San Donato circuit is a former freight train rail yard in Bologna, that has been lately redeveloped by RFI for other use. The circuit has been built respecting the current regulations and providing CE certification of infrastructure, energy and CCS subsystems.

Today, San Donato circuit is a railway test circuit suitable for:

- This railway area has been redeveloped
- Today, San Donato circuit is a railway test circuit for:
    - Dynamic test for rolling stock
    - Wayside technology innovation
    - Field testing and measurement, without interference on commercial traffic
    - Dynamic calibration of mobile measurement systems (Diagnostic trains and «Yellow Machines»)

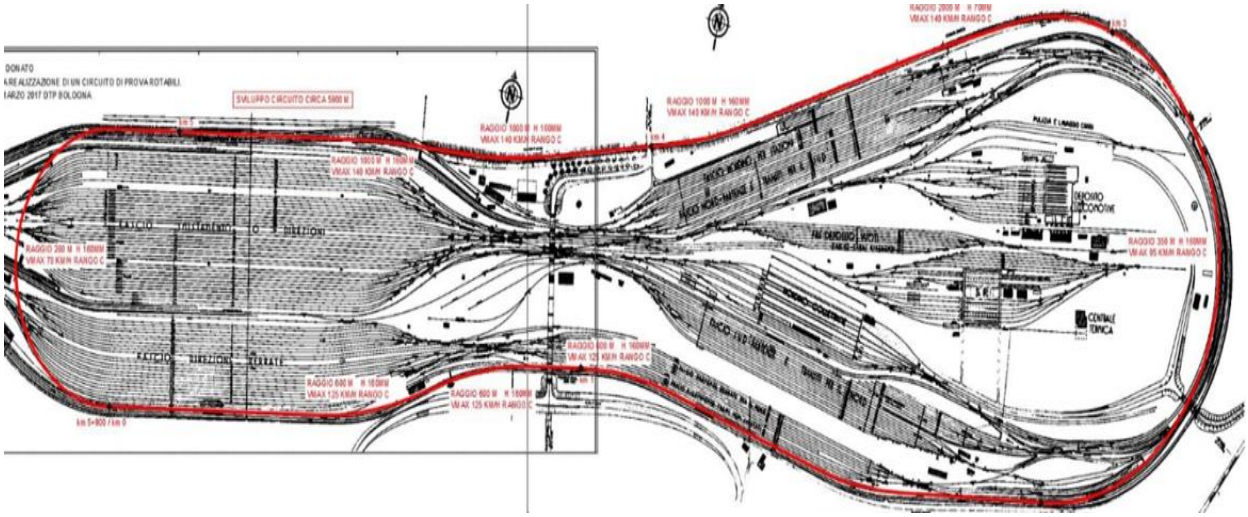

Figura 1 - San Donato Test Ring Layout

The main features of this test circuit are:

- National signalling system (SCMT)
- 4-codes reversible Automatic Coded Current Block (BACC) with three-aspects signalling with Glued Insulated Joint (GII) are placed every 650 m

Interne

- Interlocking system
- Management of 30 Track Circuits (CdB), 18 Signals, 15 Rail Switches.
- 4 stabling tracks and 2 stations
- Energy supply for railway traction at 3kV DC
- Standard Italian FS sleepers (RFI-260 for 60 UNI)

ERTMS/ETCS level 2 signalling system is currently in installation phase.

Maximum speed (C rank)	
0 – 1.420 m	115 km/h
1.420 – 2.105 m	70 km/h
2.105 – 4.028 m	100 km/h
4.028 – 5.356 m	95 km/h
5.356 – 5.749 m	115 km/h

Table 1 - San Donato Test Ring Specifics

Circuit size	
5.749 m	Length of the single track
2.000 m	Of which double track

Figure 2 - San Donato Test Ring

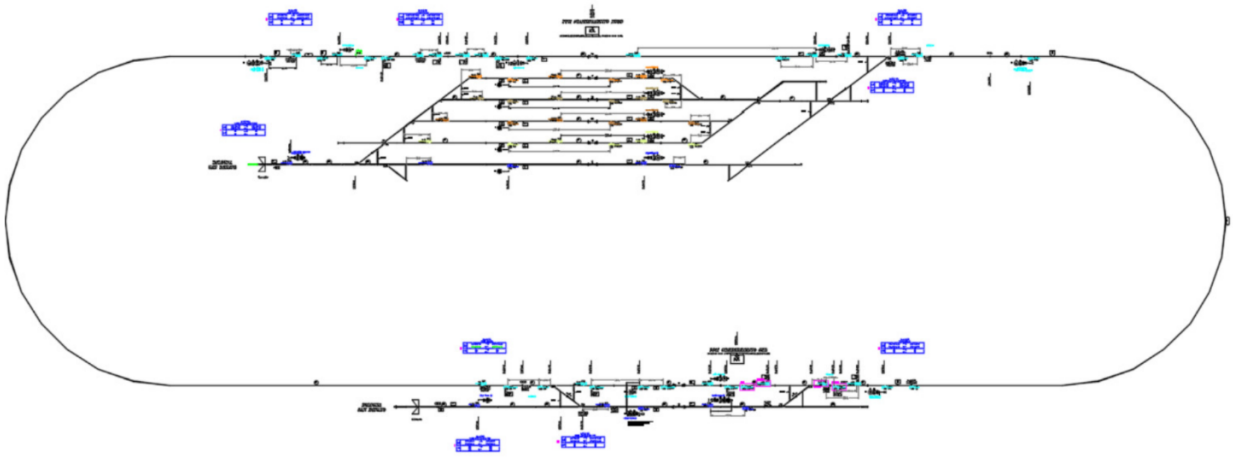

Figure 3 - San Donato Ring ERTMS Layout

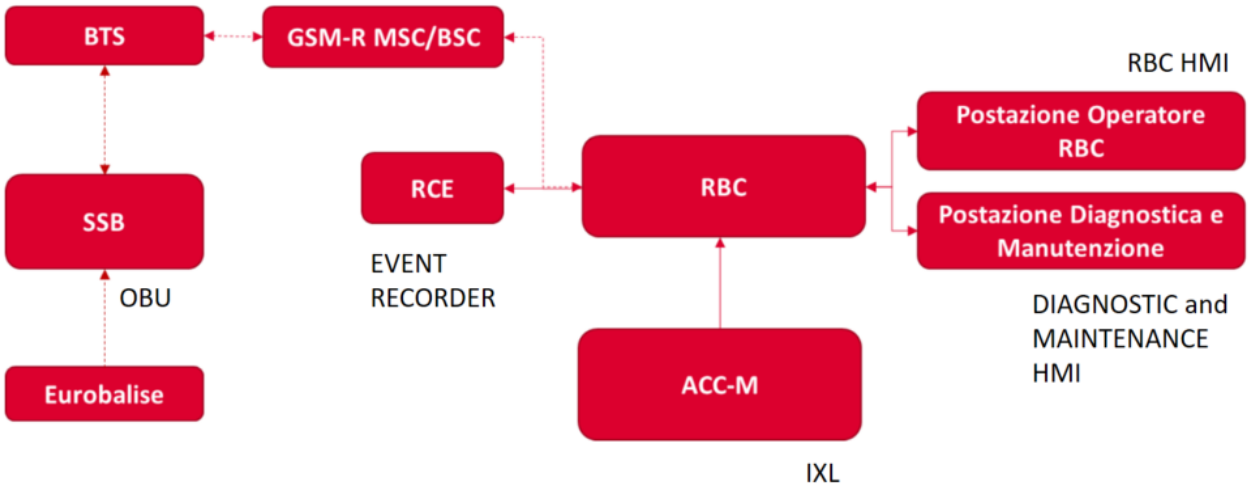

Figure 4 – Current CCS Simplified Architecture

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3.1.2 Blues Train

The "Blues" trains derive from the Masaccio platform and are equipped with diesel-electric propulsion integrated with batteries that make the train a hybrid-bimodal solution, that can also run without electrification.

These new vehicles are record-breaking in terms of performance and sustainability as they are equipped with new-generation and low-emission diesel engines (Stage V) integrated with batteries allowing emission and noise reduction.

The trains can run up to 160 km/h on electrified lines with great travel time savings.

On-board technologies include smart air-conditioning systems capable of adapting to internal conditions such as temperature and the number of passengers on board, LED systems that contribute to saving energy, video surveillance for improved safety of passengers, WiFi connection, 220V electrical and USB sockets and space for bikes and baggage.

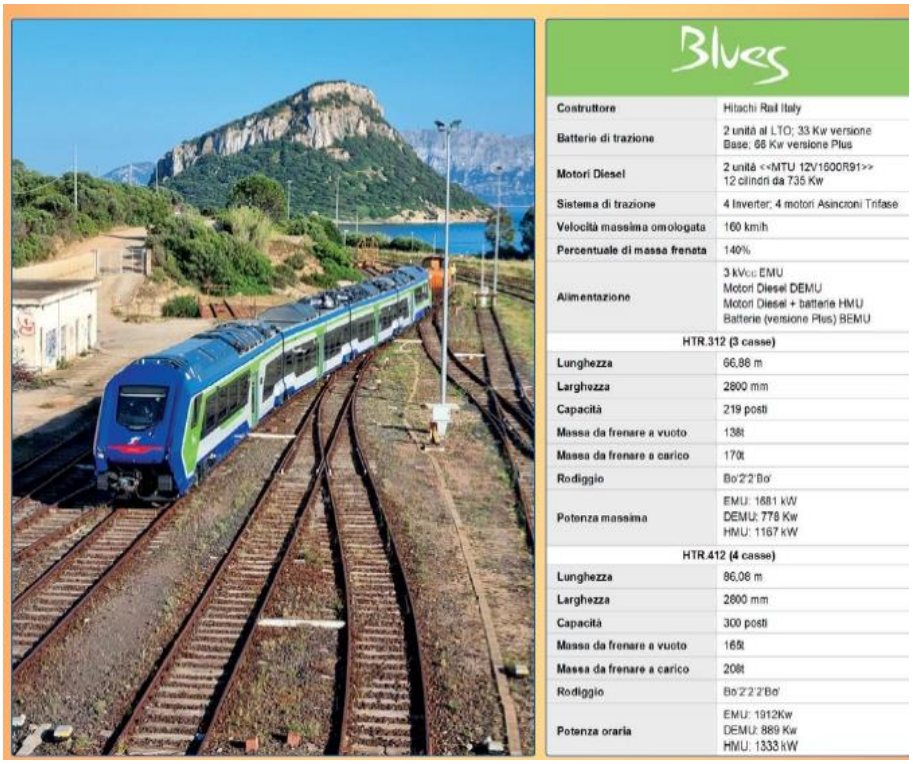
A dedicated area and toilet are available for people with reduced mobility who can also benefit from enhanced ease of access.

Main Blues train features are:

- TSI standard
- ERTMS fitted
- Tri-modal (Diesel, Pantograph, Battery (Hybrid))

Interne

Figure 5 - Blues Train



Blues	
Costruttore	Hitachi Rail Italy
Batterie di trazione	2 unità al LTO; 33 Kw versione Base; 66 Kw versione Plus
Motori Diesel	2 unità <<MTU 12V1600R91>> 12 cilindri da 735 Kw
Sistema di trazione	4 Inverter; 4 motori Asincroni Trifase
Velocità massima omologata	160 km/h
Percentuale di massa frenata	140%
Alimentazione	3 kVcc EMU Motori Diesel DEMU Motori Diesel + batterie HMU Batterie (versione Plus) BEMU
HTR.312 (3 casse)	
Lunghezza	66,86 m
Larghezza	2800 mm
Capacità	219 posti
Massa da frenare a vuoto	138t
Massa da frenare a carico	170t
Rodiggio	Bo'2'2'Bo'
Potenza massima	EMU: 1681 kW DEMU: 778 Kw HMU: 1167 kW
HTR.412 (4 casse)	
Lunghezza	86,06 m
Larghezza	2800 mm
Capacità	300 posti
Massa da frenare a vuoto	165t
Massa da frenare a carico	208t
Rodiggio	Bo'2'2'2'Bo'
Potenza oraria	EMU: 1912Kw DEMU: 889 Kw HMU: 1333 kW

Figure 6 - Blues Train Data Sheet

3.2 LABORATORY

WP39 includes test activity that will be performed in a dedicated laboratory set in the Hitachi premises in Genoa.

This laboratory will be designed and implemented to test prototype across various test scenarios. When possible, prototypes will be connected to the same components present in the operating system or to emulators acting like the real components.

Since the main objective of laboratory activities is to verify functionalities and anticipating integration between sub system, the air gaps are out of scope of test environment.

The main benefits consist in minimizing field testing duration, define the optimal configuration (of subsystems as well as scenarios), and proactively address potential issues. One key advantage is the ability to conduct tests without using the actual railways assets, this results in an effective cost-management reducing the utilization of trains and time slots and pushing test beyond the limit of real components that often cannot be updated or modified.

3.3 TRAIN AUTOMATION TECHNOLOGIES DEPLOYMENT IN WP39 DEMONSTRATOR

The present section aims to briefly describe the HW and SW modifications that will be realized to allow the demonstration of the ATO up to GoA4 and Remote Driving technologies as expected by WP39 of R2DATO project. In the following sections is provided a high-level description of the needs at trackside and train level. The final physical architecture could differ from the following description.

However the railway system architecture taken as reference is the one defined in the logical layer of X2RAIL-4 herewith reported:

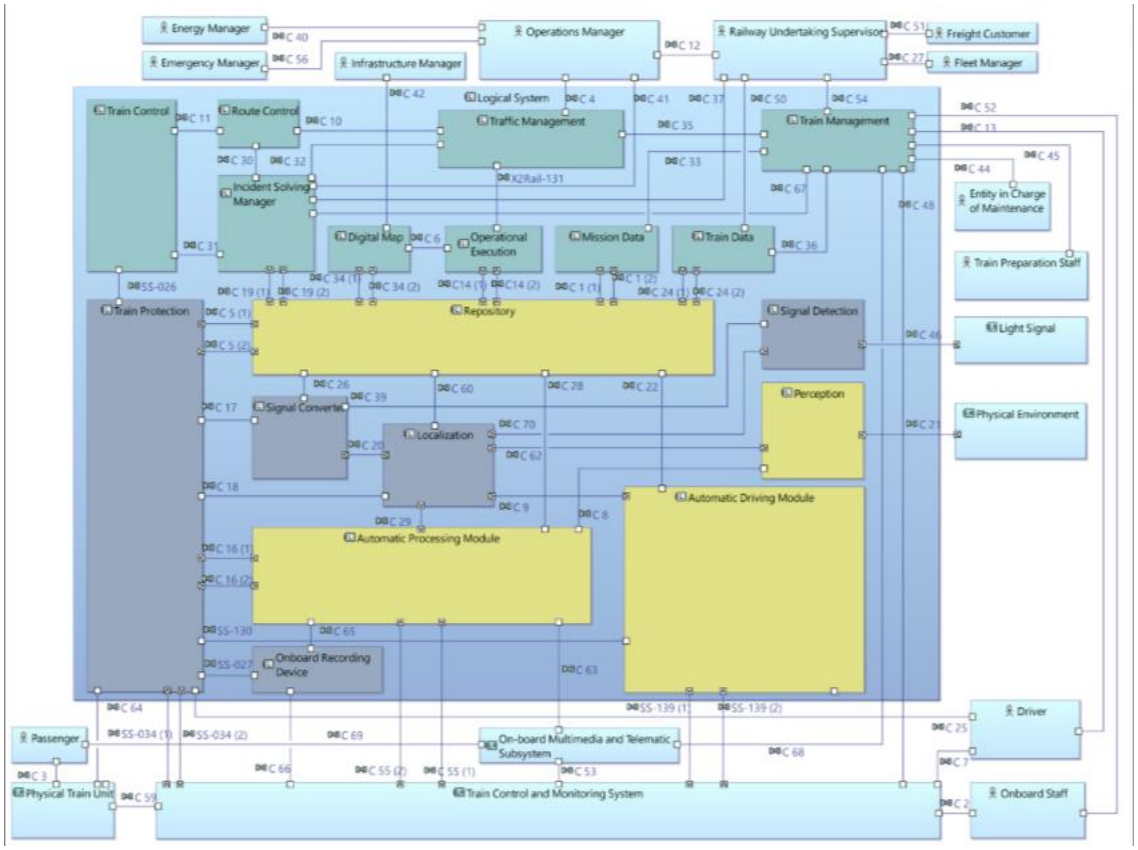


Figure 1 – Railway System logical layer of X2RAIL-4

3.3.1 San Donato Ring integration

San Donato Ring is an infrastructure that will be equipped with an ERTMS/ETCS level 2 signalling system allowing the train to run up to 115 km/h in Full Supervision.

To realize the demonstrator, the standard process (verbal communication) to authorize the train movement will be kept: it will be responsibility of the test leader in communication with the on-board driver to supervise the behaviour of the system under test (ATO up to GoA4 or Remote Control) and to take action if needed.

It is in charge of Demonstrator to define safety procedure to be applied during the execution of test.

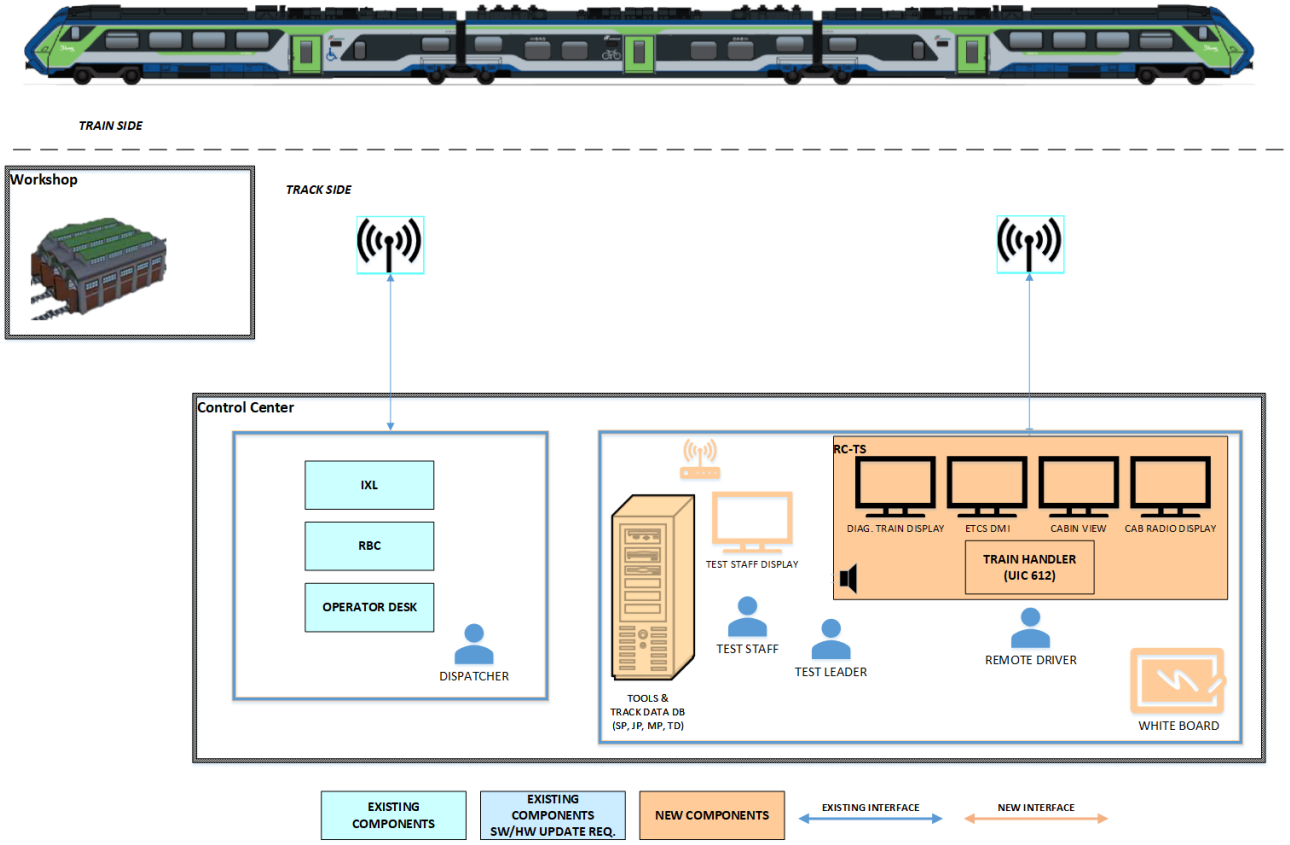


Figure 2 San Donato demonstrator, scheme representing equipment to be installed at track side.

Facilities and services required to track side are presented in the following sub-section.

3.3.1.1 Control Center

A room or a dedicated area in San Donato Control Center will be required to install remote control track side equipment. This area shall provide basic services (power supply, lights, communication etc.) to host the following people:

- Test staff: in charge to ensure the test realization (set-up, data integration, diagnostic collection and analysis)
- Remote driver (provided by demonstrator): in charge to execute standard train operation procedure (verbal communication with dispatcher for the movement authorization) as well as to drive the train remotely.
- Test leader: in charge to lead the test realization by coordinating activities between on board and trackside staff.

Note: dispatcher is expected to be hosted by a dedicated area in the control center.

Figure 3 Remote Desk to be installed in the control centre.

3.3.1.2 Workshop

San Donato demonstrator shall provide a workshop for recovering the train during installation phase.

3.3.1.3 Slots

San Donato demonstrator shall provide time-slots to book the infrastructure for test purposes.

3.3.1.4 Drivers Dispatcher and Preparation staff

San Donato demonstrator shall provide Drivers, Dispatcher and Train Preparation staff for the test purposes.

3.3.1.5 Data

San Donato demonstrator shall provide:

- scheme plans of the infrastructure, including those areas without ETCS;
- infrastructure description in terms of SP following the requirements defined by SS126 and Application Guide;
- 3D geographical data.

3.3.2 HTR312 (Blues) integration

The train HTR312 will need HW, electrical and SW modifications (only in EMU modality composition 3 pieces) to support ATO GoA4 and Remote Driving functionalities. The following scheme presents the new devices and interfaces to install.

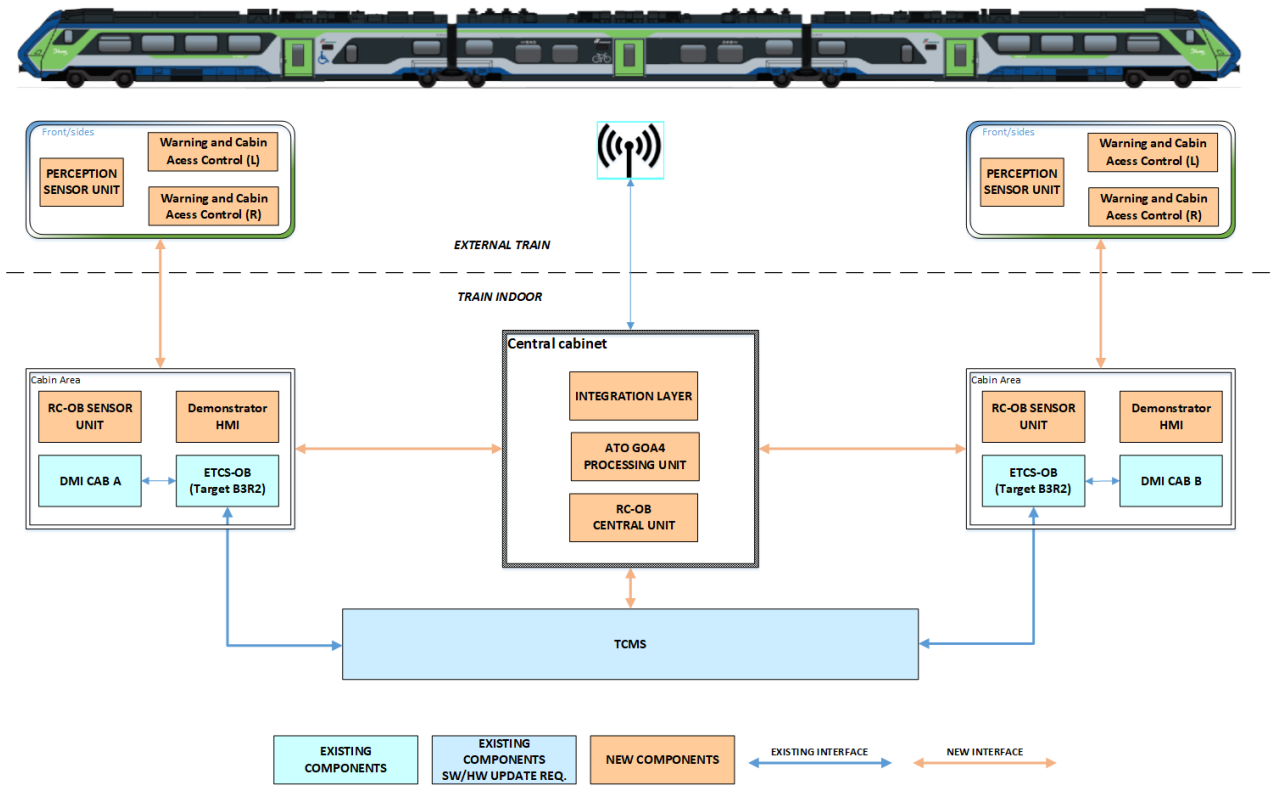


Figure 4 San Donato demonstrator, equipment to be installed in the train (indoor and externally).

3.3.2.1 Data

The proposal assumes the availability of:

- Traction and brake characteristics
- Train data
- Reference point locations in relation to the antennas (GPS and BTM)

3.3.2.2 Pre-requirements

The proposal assumes the availability on the train of:

1. GPS antenna
2. 5G mobile communications antenna
3. Related RF cables from antennas into the train
4. Office area (tables, chairs, power and data sockets) for hosting at least 4 test staff members
5. Demonstration area for hosting visitors equipped with monitors
6. Power supply
7. Depot facilities for mechanical and electrical activities

3.3.2.3 Devices to be installed

The train will be equipped with the following devices:

- Central Cabinet
- RC-OB Sensor Unit (one for each cabin)
- HMI Demonstrator (one for each cabin)
- PERCEPTION Sensor Unit (one for each front train)

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- Warning and Cabin Access Control (one for each side of the cabins)

CENTRAL CABINET

It is an industrial cabinet with the following characteristic:

- Dimensions: 1500mm x 600mm x 595mm
- Weight: 31,5kg
- Installation: placed on the train floor without anchorage

Its main function is to host the following components:

1. ATO-GoA4 Processing Unit:
   - ADM – rack 19’ 3U
   - APM & REP – rack 19’ 3U
   - PERCEPTION Control Unit
2. RC-OB Central Unit– rack 19’ 3U
3. INTEGRATION LAYER:
   - Router(s)
   - Industrial PC
   - circuit breaker panel
   - display/tablet

Figure 5 Picture of the Central Cabinet.

PERCEPTION SENSOR UNIT

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It is a custom cabinet with the following characteristic:

- Dimensions: 1450mm x 360mm x 400mm
- Weight: 28kg
- Installation: could be external (on the front of the train) or internal (in the cabin)

Its main function is to host the sensors needed for obstacle detection.

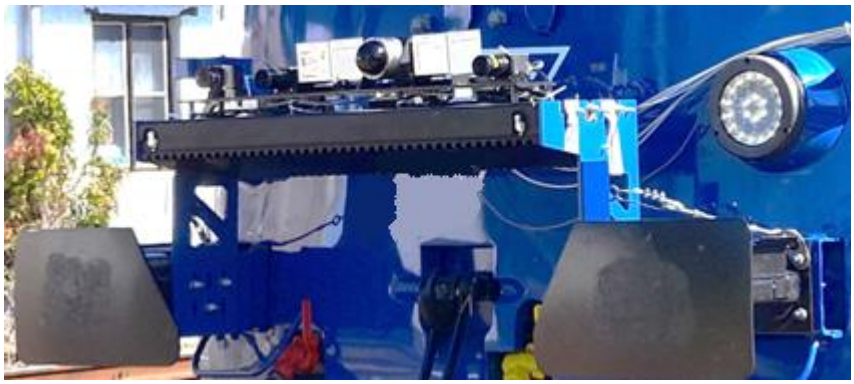

Figure 6 Picture of the Sensor Unit.

WARNING AND CONTROL CABIN ACCESS

It is an optional custom box to be installed on the sides of the trains with the purpose to realize an HMI allowing interaction with human being to facilitate boarding procedures.

RC-OB SENSOR UNIT

It is a collection of components needed by the Remote Driving technology like cameras and microphones, Video streaming encoder, Audio encoder.

DEMONSTRATOR HMI

It is an additional multipurpose interface implementing functionalities like:

- Diagnostic for test staff (ETCS data; Mission data; Journey Profile data; Remote Control data; Localization data; Test script data);
- Isolation button (override function for train driver)
- Missing system input/output: for test staff to fill gaps on interfaces (e.g. between train and system) or gaps on functionalities (e.g. train orientation and position after wake up)
- Remote Driving handover button

CABLING

The external equipment is connected by floating cables sticked on the internal train sides, the nearest windows will be used to reach the internal part of the train.

Internal cabling shall be routed using raceways along walls or roofs.

Interne

3.3.3 Prototypes and Emulators

For realizing S. Donato tests the following prototypes (with respect to X2Rail4 logical architecture where applicable) will be integrated in the demonstrator:

- APM;
- ADM;
- REP;
- PER (including sensors);
- RC-OB (including sensors);
- RC-TS.

The functionalities not covered by the previous list of prototypes will be realized by emulators or adapters. The expected emulators/adapters are:

- Localization->emulated exploiting GPS receiver and ATP diagnostic (balise detection);
- FRMCS->replaced by public 4g/5g communication services (see Figure 7 for available coverage);
- TCMS specific functions-> a set of TCMS functions will be realized by adapters or manual procedure (more details are available in 3.3.4);
- ETCS specific functions-> a set of ETCS functions will be realized by adapters or manual procedure;
- Train management (TM)-> a set of functions aimed to emulate the train planning as done through Railway Undertakings;
- Traffic management (TMS)-> a set of functions aimed to emulate the route setting and allocation to trains.

Interne

Figure 7 Description of public radio mobile communication coverage.

3.3.4 Train functions and interfaces

Deploying of Remote Driving and ATO over ERTMS with GoA4 requires to make an update on the pilot train to realize needed interfaces and functionalities, more details are provided in the following lists.

Interfaces:

- the train shall expose interface C55; [6]
- the train shall expose interface SS139; [17]
- the train shall update interface SS34. [18]

Train functions:

- Driving mode management
- Master controller (traction/brake)
- Desk activation
- Parking brake
- Pantograph
- Main switch
- Driving direction
- Holding brake
- Doors
- External lights

- Wipe and wash equipment
- Operational brake test
- Set TCMS status (Ret. of service, Shutdown)
- Remote wake up

3.4 FUNCTIONS UNDER TEST

The objective of this demonstrator is to realize automatic train operations using those basic set of functionalities (designed by the R2DATO project) allowing to realize a complete train service (starting from the wake up in the morning and ending to recovery in the depot at night).

The railways environment used to exercise these functionalities will be representative of a real railway for what concern the availability of trackside capabilities. There will be areas controlled by the operational centre without signalling system as well as areas completely equipped with an ETCS level 2 signalling system.

For this purpose, the demonstrator shall be equipped with new technologies like “Remote Driving” and “ATO up to GoA4” (including Automatic Functions, ATO technology, Perception).

In the following table, the functions under test for each technology are listed.

Function	Technology	Description
Remote Control of Train Brakes	Remote Driving	RD can use brakes also in monitoring state, then brakes remote control shall be independent from the other control. Note: When RD is in monitoring mode, he/she could be seen as a supervisor of train movement able to command brakes (similar to ATP).
Remote Control of Train Horn	Remote Driving	RD can use horn also in monitoring state, then horn remote control shall be independent by the other control.
Remote Control of Train’s other Functions	Remote Driving	These train functions will be controlled remotely: Pantograph Main switch Driving direction Traction Holding brake Doors Parking brake

Interne

		External lights Wipe and wash equipment Demist Defrost Operational brake test Set TCMS status (Ret. of service, Shutdown).
Mirroring of ETCS DMI	Remote Driving	RD will be able to use the Remote ETCS DMI for exchange of data with on board ATP only for the scenario relevant use.
Handover at standstill	Remote Driving	Handover functionalities will be carried only through an intermediate step by deactivating the cab. Train control leadership negotiation will be managed by the train itself with the principle of only one cab active at time.
Manage Remote Driving Track Train data communication	Remote Driving	Management will be focused on: setup, closure, buffering and performance monitoring. Cyber security it is out of scope.
Provide to RD voice communication services	Remote Driving	Basic and simplified voice communication services (between RD and RUS/IM-OM/Depot-OM).
Mirroring of train status and other diagnostic information	Remote Driving	Train status and other diagnostic information will be available for consultation to RD.
Manage dedicated Remote Driving DMI	Remote Driving	Dedicated Graphic Interface for RD (e.g. log in, train selection, mode selection, warnings).
Manage RD vitality	Remote Driving	Check of RD vitality when in controlling mode and brake intervention in case of missing vitality.
Manage RD user profiles	Remote Driving	Only one user profile will be configured.
Mirroring view and sounds sensed from train cabin	Remote Driving	Video and sound acquired transmitted and rendered to RD both in monitoring and controlling mode.
Manage State Transitions	ATO up to GoA4	The components of the ATO up to GoA4 system shall evolve following the conditions described in SRS and set of active functions shall be updated.

Interne

Reporting Management	ATO up to GoA4	APM and ADM shall share the information needed by REP to make and transmit Status Reports.
Monitor Overall Train Status	ATO up to GoA4	The system updates the value of each state or variable that can influence its behaviour (e.g. leadership within the train) or that shall be reported to external components. This monitoring encompasses modules of the consist and information from track side (e.g. regarding acknowledgment of tasks with staff intervention).
Mission Execution	ATO up to GoA4	It is the macro function in charge to realize the Mission Profile
Task Scheduling	ATO up to GoA4	Definition of task sequence to be executed, these tasks can be carried out also in parallel. This function is also responsible to verify the overall conditions needed to enable a task execution.
Mission Execution/TJP	ATO up to GoA4	Depending on GoA, during the Journey Profile APM shall supervise the modules of its consist and realize departures.
Mission Execution/TClear	ATO up to GoA4	MP includes tasks to be performed by staff. An acknowledgment from Train Management is required when a human intervention is finished or failed.
Mission Execution/TST	ATO up to GoA4	RU is responsible of train state setting by planning a dedicated task on the MP. APM is in charge to execute it considering conditions (e.g. absence of passengers) and status of any Journey.
Mission Execution/TCG	ATO up to GoA4	The change of GoA needs different check conditions and actions depending on the GoA requested. It implies the selection of train orientation and vigilance deactivation for GoA3 or 4.
Mission Execution/Mission Termination	ATO up to GoA4	The system shall report the Mission Profile termination and close the connection with Train Management. These actions shall be realized when the

Interne

		condition to detect that a Mission Profile is terminated or terminating are met.
Mission Execution/Idle detection	ATO up to GoA4	Function in charge to detect idle period along the mission profile, where a Retention of Service shall be applied.
Unattended Train Doors Operation	ATO up to GoA4	Extension of GoA2 functionalities to include TDO at the start of Journey and at the End of Journey- in GoA3 and 4.
Evaluated/Reflexive Reaction	ATO up to GoA4	APM shall realize a set of coded action when an incident is detected.
Track Train communications management	ATO up to GoA4	Management of communications between the three main track entities: ISM, TM, TMS.

Table 1: Functions tested in San Donato Demonstrator.

In addition to previous functions other elements will be developed to allow tests execution, in this case development shall be understood in its general meaning that is not only including SW or HW components, but also manual procedures. These elements, listed in Table 2, will not be under test.

Function	Technology	Description
Train Wake up	EF to TCMS	TCMS performs the train wake up leaving the train in stand-by but ready for service.
Other Train functions	EF TCMS	Any function needed by prototypes
TP functions	EF TP	Any function needed by prototypes
Other Track side functions	EF Track side	Any function needed by prototypes

Table 2: Functions developed, but not under test in San Donato Demonstrator.

4 ATO SCENARIOS AND USE CASES

4.1 USE CASES

In the following table the use cases applicable to S.Donato demonstrator are presented. The first column gives the identification number and name of use case referring to the documents **Errore. L'origine riferimento non è stata trovata.** and [14].

NOTE 1: The use cases defined in **Errore. L'origine riferimento non è stata trovata.** and [14] have been developed prior to the R2DATO design activities, then the use cases developed in this

demonstrator will be an evolution of the original ones to be compliant to new specifications (D6.5) and to the constraints set by S.Donato test ring and BLUES train.

NOTE 2: Handover from RD to/from Autonomous Driving while the train is running is out of scope of WP39. The switch of responsibility between Remote Driver and ATO up to GoA4 is realized at standstill by means of remote cab deactivation followed by a virtual cab activation.

NOTE 3: multiple Remote Drivers interaction is out of scope of WP39 as well as UC/functions related to movements between two Remote Control areas.

NOTE 4: inaccurate stop is out of scope of WP39.

NOTE 5: MP update is out of scope of WP39.

Use Cases	Technology	Description
UC5.4-001; Register a train at an RSC	Remote Driving	A train registers to the remote control centre, when the registration is completed a RD will be able to observe, monitor or control the train.
UC5.4-009; Log-in on a registered standby train	Remote Driving	RD selects the train to be monitored.
UC5.4-010; Take control of a monitored standby train	Remote Driving	RD takes control of a train not yet controlled by anyone (local driver or ATO)
UC5.4-013; Perform ETCS start of mission procedure by remote driver	Remote Driving	RD performs "Start Up dialogue sequence" selecting "NTC" level and requesting shunting
UC5.4-047; Demote a train from operative to standby by remote driver	Remote Driving	RD is controlling the train and performs all actions needed to Shutting Down the train (standstill, ETCS end of mission, parking brake applied, shutting down request).
UC5.4-016; Stop monitoring a train by a remote driver	Remote Driving	This U.C could represent a possible evolution of UC5.4-025 (alternative to UC5.4-024): RD release the cab and stop controlling the train, train responsibility is in charge of TCMS and transferred to ATO up to GoA4 as soon as a virtual desk is activated. In this phase alarms are managed by ISM (with support of APM) then RD can stop monitoring the train (transition to mode observing or to mode uninvolved).
UC5.4-017; Confirm remote driver vitality by remote driver	Remote Driving	While RD is controlling and the train is moving (above all when ATP realize a limited supervision as in the case of

Interne

		shunting movements), vitality is checked and proper brake reaction is applied when triggered.
UC5.4-024; Perform routine driving by remote driver	Remote Driving	This U.C could represent a possible evolution of UC5.4-025: RD release the cab and stop controlling the train, train responsibility is in charge of TCMS and transferred to ATO up to GoA4 as soon as a virtual desk is activated. In this phase alarms are managed by ISM (with support of APM) but RD can continue monitoring the train (transition to mode observing or to mode uninvolved) and intervene (e.g. by braking or activating the horn) if necessary.
UC5.4-025; Move train from yard to platform by remote driver– free track	Remote Driving	RD takes control of the train and realizes the planned movement from yard /depot to a track equipped with signalling. RD releases the cab occupation and stops to control the train (while the train is at standstill). No handover performed, ATO will ask control following its principles based on cab status and MP indications.
UC5.4-037; Take responsibility of a GoA4 train in degraded ATO situation	Remote Driving	In this UC RUS is informed about an incident during GoA4 Train Operations (e.g. failure of perception function), then assigns to RD the task to take control of the train asking to reach the first rescue area.
13.3.1 Awakening sequence of autonomous train 13.3.3 Initialization sequence for a multiple unit movement	Automatic Functions	In this UC the system establishes the communication with trackside and starts MP execution depending on overall conditions (e.g. leadership, cab status, alarms, etc.).
13.3.5 Determine and select travelling direction	Automatic Functions	
13.3.4 Train Protection configuration	Automatic Driving and Automatic Functions	The ETCS data entry procedure is performed by the system
13.3.6 Deactivate vigilance	Automatic Functions	

13.4.2 Check departure conditions except signalling 13.4.6 Authorize departure of autonomous train 13.6.4 Supervise departure of a passenger train 13.4.7 Determine stopping point for a freight or passenger train 13.4.8 Traction and brake control 13.4.1 Move autonomous train 13.4.9 Request holding brake	Automatic Driving and Automatic Functions	
JP update/MA update	Automatic Driving	This use case allow to demonstrate the benefit of ATO in terms of energy saving
13.6.5 Door opening (passenger train)	Automatic Driving and Automatic Functions	
13.6.6 Door closing (passenger train)	Automatic Driving and Automatic Functions	Nominal sequence
13.6.6 Door closing (passenger train)	Automatic Driving and Automatic Functions	Degraded scenario of crowded platform only lab.
13.2.7 Validate human interaction	Automatic Driving and Automatic Functions	EoJ and TClear
Automatic turn back	Automatic Driving and Automatic Functions	
13.2.5 Park autonomous train	Automatic Functions	
13.2.6 Switch to retention of service	Automatic Functions	
13.7.12 Stop at next station or rescue point	Automatic Driving and Automatic Functions	Only lab PERCEPTION Off or in Failure

Interne

Loss of op.cond.- JP incomplete	Automatic Driving and Automatic Functions	
Loss of op. cond.- T_NVCONTACT timeout	Automatic Driving and Automatic Functions	Only lab
13.8.2 React on obstacle	Automatic Driving, Automatic Functions and Perception	
13.4.4 Activate horn	Automatic Functions	
13.9.16 Obstacle when door is closing	Automatic Functions	Only lab NOTE: out of scope functions related to PIS.
13.10.5 Point failure without movement permission 13.7.2 Unexpected stop 13.7.4 Restart after unexpected stop	Automatic Driving, Automatic Functions	Only lab
Change of GoA requested by MP	Automatic Driving, Automatic Functions and Perception	
Remote driving handover to GoA4.	Automatic Functions	
Remote driving handover from GoA4.	Automatic Functions	

Table 3: WP5 and X2Rail4 use cases applicable in San Donato demonstrator. Applicability shall be understood as specified in NOTE1.

4.2 SCENARIOS

Use Cases will be realized within the following set of scenarios:

1. Shunting movement in remote driving until transition in full supervision.
2. Train operation in GoA4 (after Remote Driving handover) including multiple train service (with multiple stops) and “end of service”.
3. Train operation in Remote Driving (after GoA4 handover) including train stabling in depot.
4. Wake up in GoA4 and train operation (in GoA4) with automatic turn back, reaction to obstacle, stand-by/Energy Saving (parking).

Interne

5. Wake up in GoA1 train operation (in GoA2), transition in GoA4, train operation (in GoA4), transition in GoA2, train operation (in GoA2).

In the next sections a description of each use case is provided.

4.2.1 Scenario 1: Shunting movement in remote driving until transition in full supervision

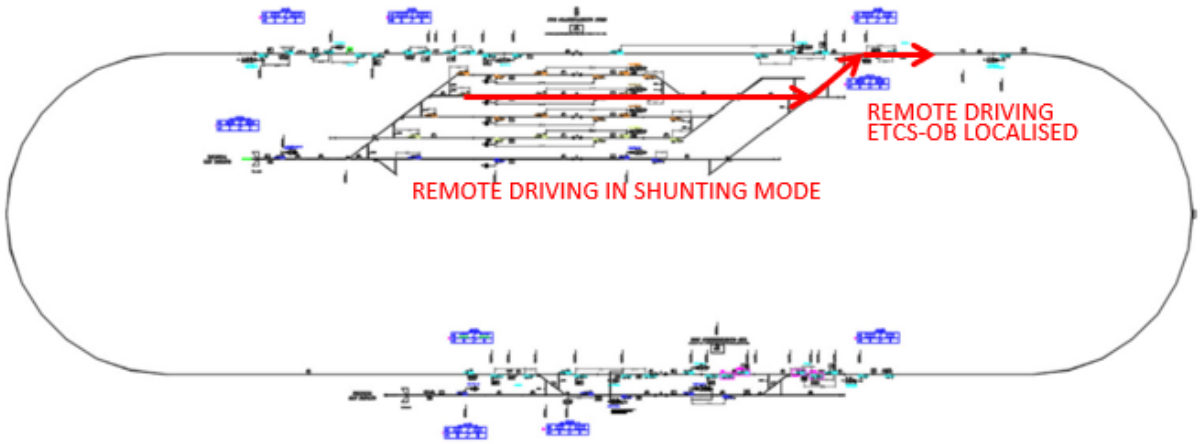

Figure 8 Scenario 1.

Scenario field	Description
ID	SCENARIO 1
Scenario name	Shunting movement in remote driving until a defined point of main line where ETCS-OB is localised.
Main actor	Remote Driver
Scenario description	RUS starts his/her planned duties, then train is woken up remotely and Remote driver receives his/her tasks (remote-control mission). The startup phase of the components and the operations to bring the train in ready for service is out of scope of this scenario. The basic connectivity to trackside is established and the train can be controlled by Remote Driver. RD and Operations Manager of the depot/yard agree on which movements will be performed and when, the RD starts controlling the train and executing his/her remote-control mission. The task of RD is completed when the train has reached the final position and its “Train Context State” is “Service Retaining”.
Main goal	At the end of this scenario, the train is localised and ready for service at any “Operating Context State” (D6.5). By executing this scenario, the system reached the status required by scenario 2 as preconditions.

Preconditions	Train parked in the depot/yard (not equipped with ETCS), “Train Context State” is “Sleeping” (D6.5), Mission Profile is defined, no position information available in ETCS. Remote-control mission is ready.
MP	Available, but not relevant.
JP	Available, but not relevant.

Table 4: Scenario 1 Datasheet

Triggered UC	Expected Outcome
UC5.4-001: Register a train at an RSC	From the GUI of the remote-control centre, it is possible to see the pilot train in the status “registered”.
UC5.4-009: Log-in on a registered standby train	Main displays switched on showing the view as it is acquired if a cab is active. “Train Context State” is “Service Retaining”. ATO up to GoA4 available.
UC5.4-010: Take control of a monitored standby train	All the controls of the remote desk are active, remote DMI is switched on.
UC5.4-013: Perform ETCS start of mission procedure by remote driver	Shunting mode activated.
UC5.4-025: Move train from yard to platform by remote driver– free track	The train moves accordingly to remote driver commands. When the train reaches the final position of remote movement and remote driver release train control, main displays switched off.

Table 5: List of use Cases triggered by scenario

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4.2.2 Scenario 2: Train operation in GoA4 including multiple train service (with multiple stops) and “End of train service”

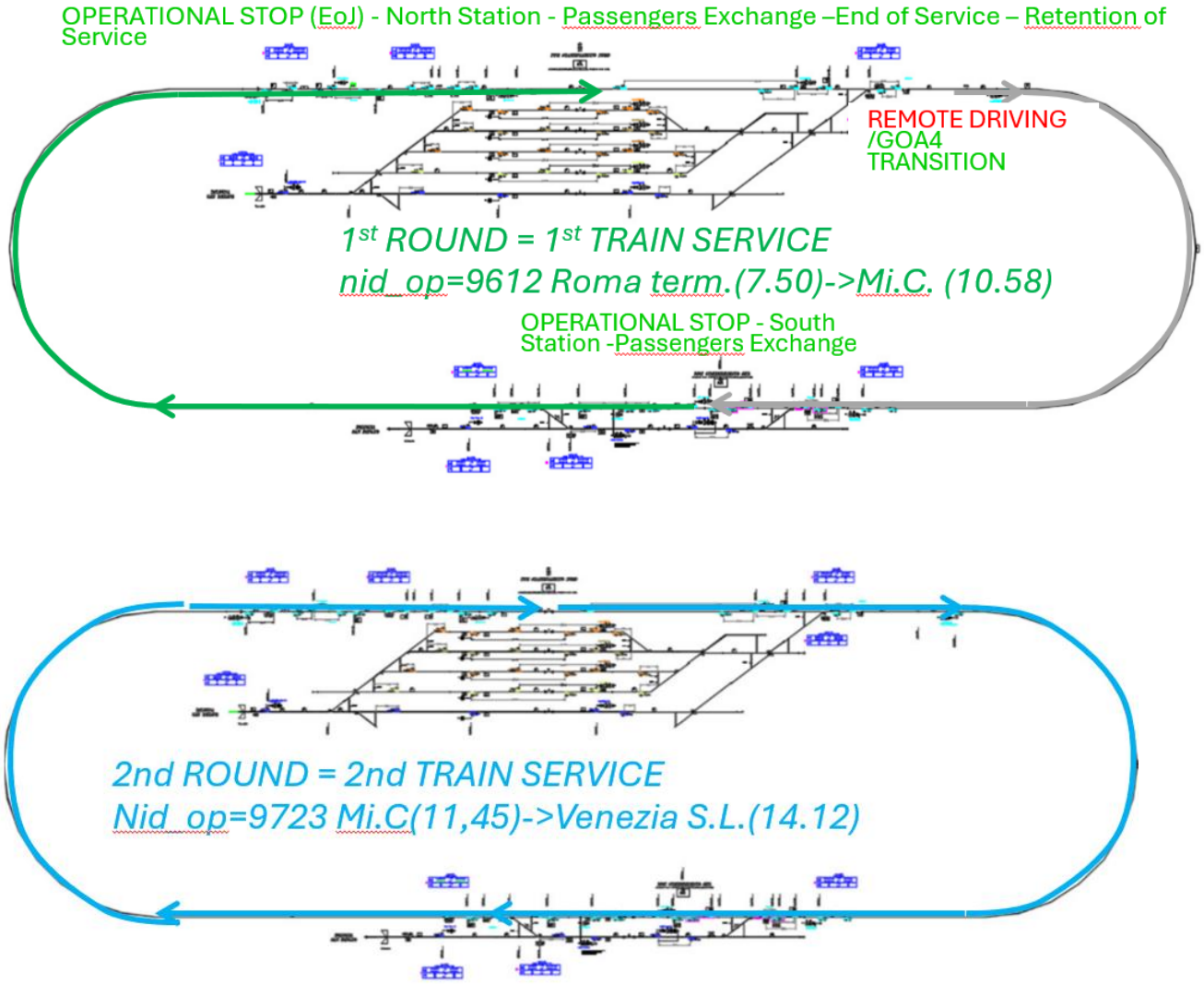

Figure 9 Scenario 2.

Scenario field	Description
ID	SCENARIO 2
Scenario name	Train operation in GoA4 including multiple train service (with multiple stops) and “End of train service”
Main actor	n.a.
Scenario description	The concept behind this scenario is to represent a typical day life of a train. This scenario could be seen as the continuation of scenario 1. The ATO up to GoA4 executes MP and takes control of the train. First movement represent a GoA4 transfer to move the train in the station

	where the first passenger service will start, cab is closed. This journey profile is realized triggering automatic train doors and automatic driving, at the EoJ doors are closed (passenger service is completed) and after the acknowledge that train is empty (absence of passengers), service retaining with energy saving is activated. At the time scheduled in the mission profile a new GoA4 transition with cab activation will be realized, train operations of the last journey profile follow. In the last station passengers leave the train, doors are closed, and after the acknowledge that train is empty (absence of passengers), shutdown procedure is initiated.
Main goal	To execute a complex mission profile, made of a sequence of journey profile and Train set status. Management of doors is done at first, intermediates and last stations. Passengers exchange and departure is supervised in GoA4 as well as the running during the movement between two stations.
Preconditions	Train is standstill, in an area equipped with ETCS, its “Train Context State” is “Service Retaining”. Mission Profile and Journey Profile already stored on board. ETCS-OB in SB with valid train position information.
MP	The mission profile contains a sequence of tasks defining requested GoA (always GoA4) and reference to JP. At the last station of the second JP, MP plans a long stop where the train shall be set to “Energy Saving” after having checked the train clearance from passengers. As last task the train is set to “Shutting down” after having checked the train clearance from passengers. All tasks have a begin trigger set as time and position constraints.
JP	In scenario 2 three different JPs are present: JP0: • Type: RS transfer without passengers • Nid_operational= 0001 • Movement: from St.P X to St.P S (*) JP1: • Type: train service with passengers • Nid_operational= 9612 • Movement: from St.P S to St.P N. JP2: • Type: train service with passengers • Nid_operational= 9723 • Movement: from St.P N to St.P N (1 loop). (*) St.P X is a point within ETCS area but beyond yard. St.P S is a point within South station. St.P N is a point within North station.

Table 6: Scenario 2 Datasheet

Triggered Use Cases	Expected Outcome
13.3.5 Determine and select travelling direction	Virtual CAB activation, APM in GoA4 state, real on board DMI activation, PER sensors activation and PER in OP state
13.3.4 Train Protection configuration	REP in OP state ETCS-OB in FS
13.3.6 Deactivate vigilance	Request of vigilance deactivation from APM to TCMS
13.4.2 Check departure conditions except signalling 13.4.6 Authorize departure of autonomous train 13.6.4 Supervise departure of a passenger train 13.4.7 Determine stopping point for a freight or passenger train 13.4.8 Traction and brake control 13.4.1 Move autonomous train 13.4.9 Request holding brake	Setting of Virtual direction ctrl in neutral When dwell time is elapsed Virtual direction ctrl in forward Train departure Train stopped at the St.P S (EoJ) and holding brake applied. Note: no Train Doors Operations are executed because of the type of TJP.

Table 7: List of use cases triggered by scenario when tasks TCG and TJP (Type: RS transfer without passengers) are in execution.

Triggered Use Cases	Expected Outcome
13.2.6 Switch to retention of service	Virtual CAB deactivated. Parking brake applied DMI monitor off.

Table 8: List of use cases triggered by scenario when task TST (Service Retaining, without Energy Saving activation) is in execution.

Triggered Use Cases	Expected Outcome
13.3.5 Determine and select travelling direction	Virtual CAB activation, APM in GoA4 state, real on board DMI activation, PER sensors activation and PER in OP state
13.3.4 Train Protection configuration	REP in OP state ETCS-OB in FS
13.3.6 Deactivate vigilance	Request of vigilance deactivation from APM to TCMS
13.6.5 Door opening (passenger train)	•At beginning of TJP: ○ as soon as TCG is completed and TJP is ongoing (needs to have ETCS in FS and ADM in AV), ADM can request doors opening. •Intermediate stops and Terminal Station (EoJ): ○ As soon as the St.P is reached
13.6.6 Door closing (passenger train)	•At beginning of TJP and for intermediate stops:

Interne

	○ When dwell time is elapsed ADM requests doors closing. •At Terminal Station (EoJ): ○ When minimum dwell time is elapsed.
13.4.2 Check departure conditions except signalling 13.4.6 Authorize departure of autonomous train 13.6.4 Supervise departure of a passenger train 13.4.7 Determine stopping point for a freight or passenger train 13.4.8 Traction and brake control 13.4.1 Move autonomous train 13.4.9 Request holding brake	Setting of Virtual direction ctrl in neutral. When dwell time is elapsed Virtual direction ctrl in forward. Train departure. Train stopped at the requested stopping points. Note: no Train Doors Operations are executed because of the type of TJP.

Table 9: List of use cases triggered by scenario when tasks TCG and TJP (Type: train service with passengers) are in execution).

Triggered Use Cases	Expected Outcome
13.2.6 Switch to retention of service	Virtual CAB deactivated. Parking brake applied DMI monitor off. Acknowledge of train clearance from passengers. Comfort services in energy saving mode.

Table 10: List of use cases triggered by scenario when tasks TClear and TST(Service Retaining, with Energy Saving activation) are in execution.

Triggered UC	Expected Outcome
13.2.5 Park autonomous train	Virtual CAB deactivated. Parking brake applied DMI monitor off. Acknowledge of train clearance from passengers. Switch-off of components Lowering pantograph Main switch off

Table 11: List of use cases triggered by scenario when tasks TClear and TST(Shutdown) are in execution.

4.2.3 Scenario 3: Train operation in Remote Driving (after GoA4 handover) including train stabling in depot

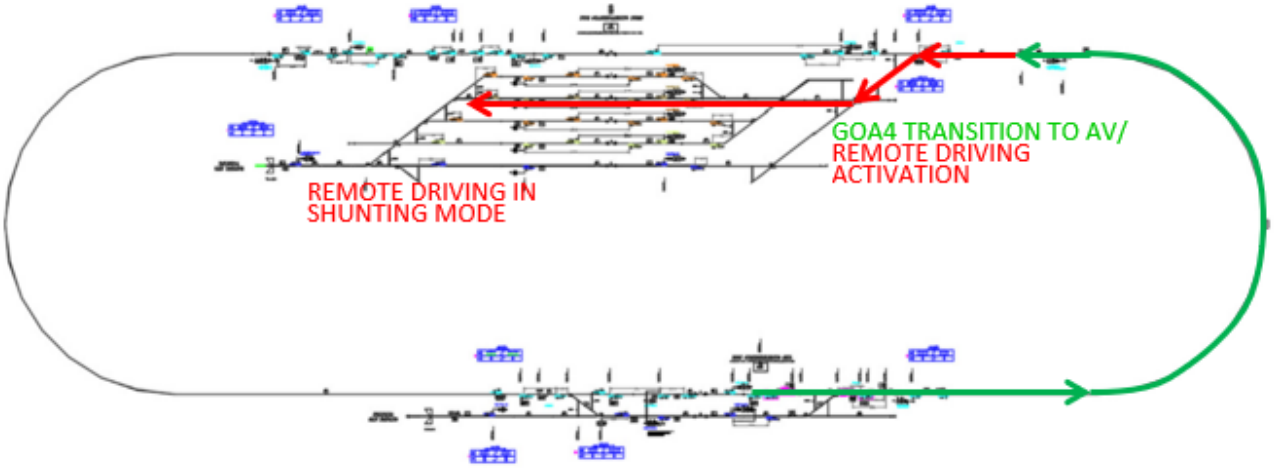

Figure 10 Scenario 3.

Scenario field	Description
ID	SCENARIO 3
Scenario name	Shunting movement in remote driving until stabling point is reached.
Main actor	Remote Driver
Scenario description	RUS continues his/her planned duties. Remote driver receives his/her tasks (remote-control mission). The train, after a GoA4 movement, is in “Service Retaining”: the basic connectivity to trackside is established and the train can be controlled by Remote Driver. RD and Operations Manager of the depot/yard agree on which movements will be performed and when, the RD starts controlling the train and executing his/her remote-control mission. The task of RD is completed when the train has reached the final position where parking is scheduled and “Shutting down” has been launched (train will transit to “Sleeping”).
Main goal	At the end of this scenario, the train is parked and set to “Sleeping” “Train context State” (D6.5).
Preconditions	Train in “Service Retaining” (D6.5) in a location still under ETCS equipped area but in the premises of depot/yard. Remote-control mission is ready.
MP	Available, but not relevant.
JP	Available, but not relevant.

Table 12: Scenario 3 Datasheet

Triggered UC	Expected Outcome

UC5.4-009: Log-in on a registered standby train	Main displays switched on showing the view as it is acquired if a cab is active. “Train Context State” is “Service Retaining”. ATO up to GoA4 available.
UC5.4-010: Take control of a monitored standby train	All the controls of the remote desk are active, remote DMI is switched on.
UC5.4-013: Perform ETCS start of mission procedure by remote driver	Shunting mode activated.
UC5.4-025: Move train from yard to platform by remote driver– free track	The train moves accordingly to remote driver commands and reaches the final position of remote movement where the parking is scheduled.
UC5.4-047: Demote a train from operative to standby by remote driver	Parking brake is applied, Lowering pantograph, Main switch off

Table 13: List of use cases triggered by scenario

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4.2.4 Scenario 4: Wake up in GoA4 and train operation (in GoA4) with automatic turn back, reaction to obstacle, stand-by/Energy Saving (parking)

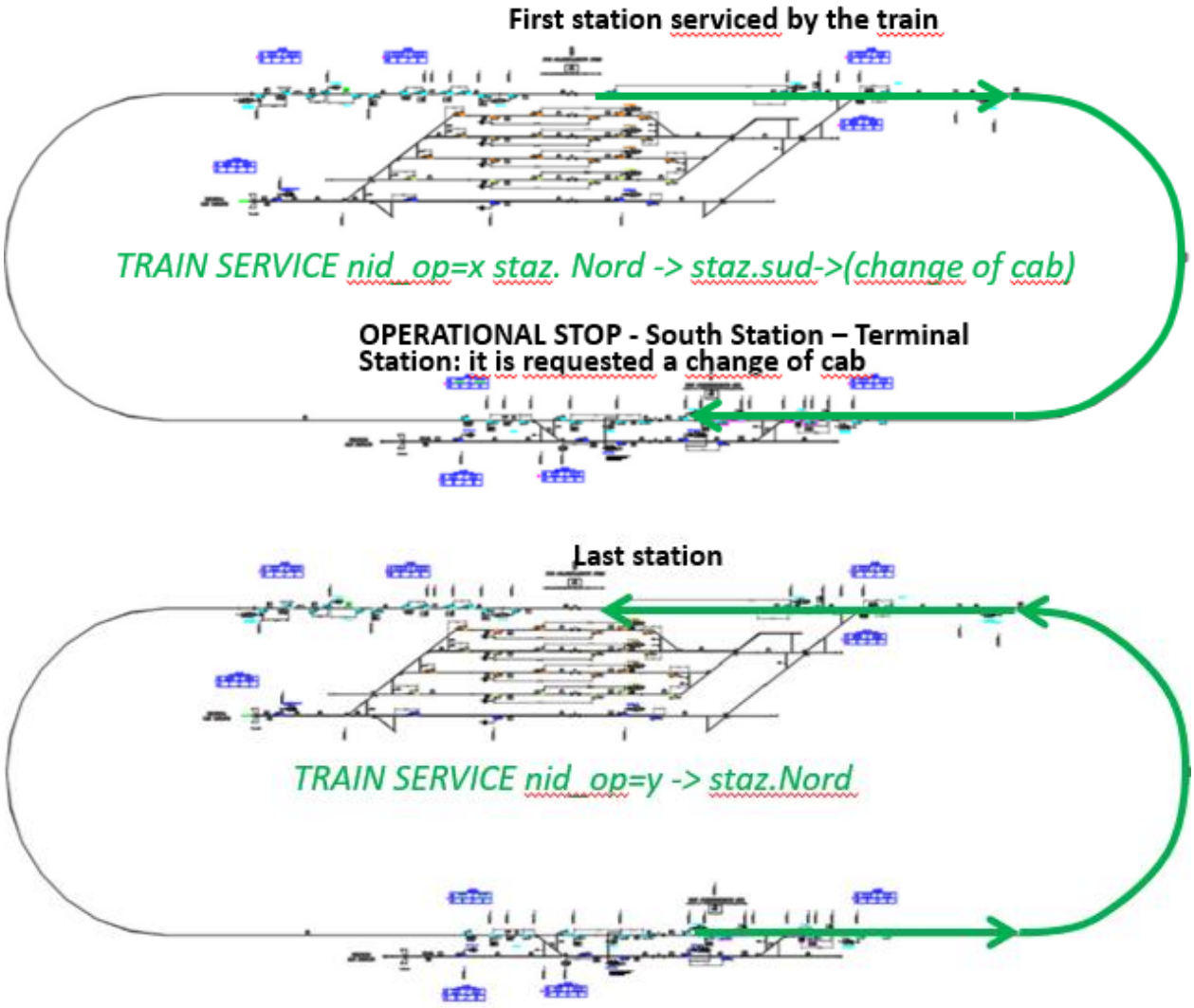

Figure 11 Scenario 4.

Scenario field	Description
ID	SCENARIO 4
Scenario name	Wake up in GoA4 and train operation (in GoA4) with automatic turn back, reaction to obstacle, stand-by/Energy Saving (parking)
Main actor	n.a.
Scenario description	The first concept behind this scenario is to demonstrate a remote wake up able to bring the train ready for service. This readiness includes ETCS-OB: wake up is realized in an area equipped with ETCS and the

	on board has stored a valid location. With respect to scenario 2, where preconditions are met thanks to a remote driving train operation, in scenario 4 GoA4 train operation are available as soon as the start-up phase is completed. The second target is to demonstrate the automatic turn back: MP contains a journey where is included an operational stop (passenger service) in a terminal station.
Main goal	GoA4 train operations after remote wake up and automatic turn back.
Preconditions	Train is standstill, in an area equipped with ETCS, ETCS-OB has stored a valid position (no cold movement detected).
MP	The mission profile contains a sequence of tasks defining requested GoA (always GoA4) and reference to JPs. The intermediate stop is realized in a terminal station (not needed to be a real terminal station), this location represents the EoJ of first JP and the SoJ of the second JP (because of the need of automatic turn back as defined in D6.5). During the change of cab, MP requests train in Service Retaining. Last MP task requests to set the train in Sleeping by launching a “Shutting down” after having checked the train clearance from passengers. All tasks have a begin trigger set as time and position constraints.
JP	In scenario 4 a train service including a change of cab is set by two JPs: JP0: • Type: train service with passengers • Nid_operational= 0001 • Movement: from St.P N to St.P S (*) • EoJ without doors closure JP1: • Type: train service with passengers • Nid_operational= 0002 • Movement: from St.P S to St.P N. (*) St.P S is a point within South station. St.P N is a point within North station.

Table 14: Scenario 4 Datasheet

Triggered Use Cases	Expected Outcome
13.3.5 Determine and select travelling direction	Virtual CAB activation, APM in GoA4 state, real on board DMI activation, PER sensors activation and PER in OP state.
13.3.4 Train Protection configuration	REP in OP state. ETCS-OB in FS.

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13.3.6 Deactivate vigilance	Request of vigilance deactivation from APM to TCMS.
13.6.5 Door opening (passenger train)	•At beginning of TJP: ○ as soon as TCG is completed and TJP is ongoing (needs to have ETCS in FS and ADM in AV), ADM can request doors opening. •Intermediate stops and Terminal Station (EoJ): ○ As soon as the St.P is reached.
13.6.6 Door closing (passenger train)	•At beginning of TJP and for intermediate stops: ○ When dwell time is elapsed ADM requests doors closing. •At Terminal Station (EoJ): ○ Case JP0 “passenger service not terminated” ▪ No closure is commanded. ○ Case JP1 “passenger service terminated” ▪ When minimum dwell time is elapsed.
13.4.2 Check departure conditions except signalling 13.4.6 Authorize departure of autonomous train 13.6.4 Supervise departure of a passenger train 13.4.7 Determine stopping point for a freight or passenger train 13.4.8 Traction and brake control 13.4.1 Move autonomous train 13.8.2 React on obstacle 13.4.9 Request holding brake	Setting of Virtual direction ctrl in neutral. When dwell time is elapsed Virtual direction ctrl in forward. Train departure. Train stopped at the requested stopping points. Detection of obstacle and approach without hit. Train service resume (departure), when obstacle is removed.

Table 15: List of use cases triggered by scenario when tasks TCG and TJP (Type: train service with passengers) are in execution.

Triggered Use Cases	Expected Outcome
13.6.6 Door closing (passenger train)	Simulation of crowded platform: doors are kept open until authorization from trackside is received
13.7.12 Stop at next station or rescue point	Reaction executed by APM due to a PERCEPTION degradation (Off or in Failure).
Loss of op. cond.- T_NVCONTACT timeout	Reaction executed by APM, when ADM transitions in DE
13.9.16 Obstacle when door is closing	Train Anomaly sent APM resume train service as soon as obstacle is removed.
13.10.5 Point failure without movement permission 13.7.2 Unexpected stop 13.7.4 Restart after unexpected stop	ATP transitions in Trip mode APM reacts to incidents keeping train standstill APM resume train service (restoring FS and train departure)

Table 16: Additional list of use cases triggered only in laboratory by scenario when tasks TCG and TJP (Type: train service with passengers) are in execution.

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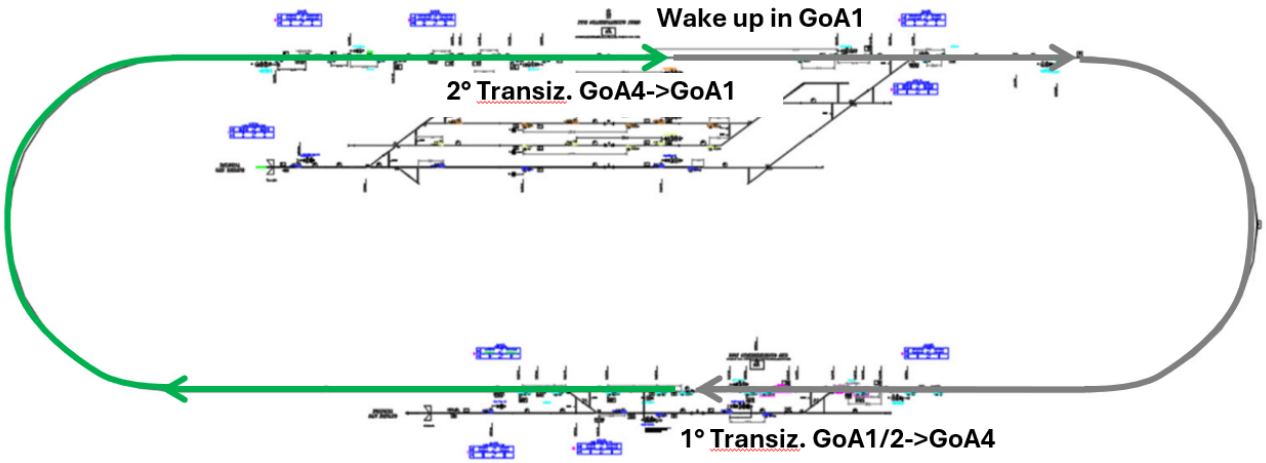
Triggered Use Cases	Expected Outcome
13.2.6 Switch to retention of service	Virtual CAB deactivated. Parking brake applied DMI monitor off.

Table 17: List of use cases triggered by scenario when task TST (Service Retaining, without Energy Saving activation) is in execution.

Triggered Use Cases	Expected Outcome
13.2.5 Park autonomous train	Virtual CAB deactivated. Parking brake applied. DMI monitor off. Acknowledge of train clearance from passengers. Switch-off of components Lowering pantograph Main switch off

Table 18: List of use cases triggered by scenario when tasks TClear and TST(Shutdown) are in execution.

4.2.5 Scenario 5: Wake up in GoA1, train operation (in GoA2), transition in GoA4, train operation (in GoA4), transition in GoA2, train operation (in GoA2)



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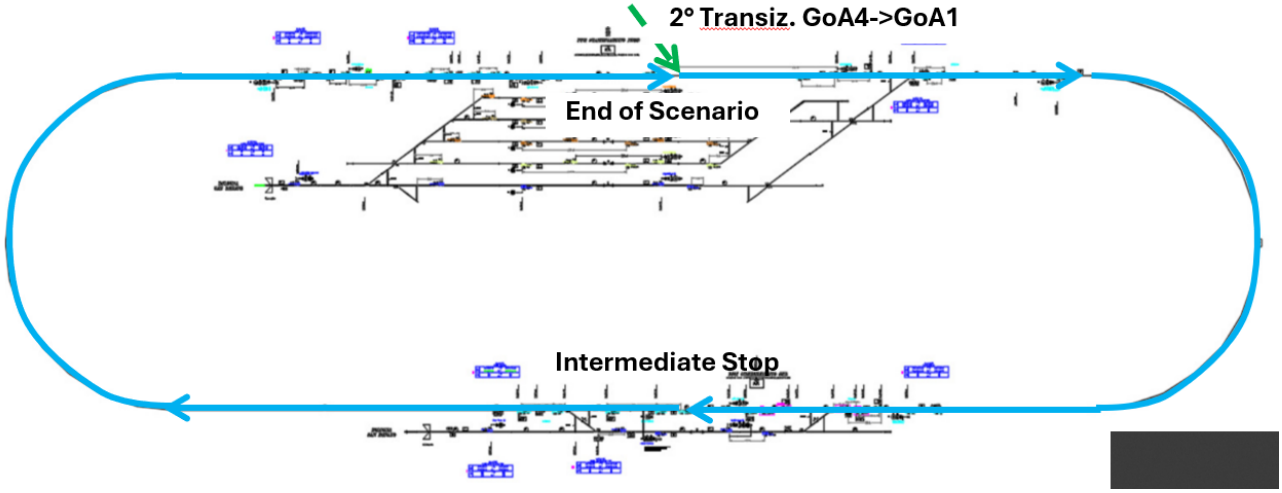

Figure 12 Scenario 5.

Scenario field	Description
ID	SCENARIO 5
Scenario name	Wake up in GoA1, train operation (in GoA2), transition in GoA4, train operation (in GoA4), transition in GoA2, train operation (in GoA2)
Main actor	Driver when in GoA2.
Scenario description	The concept behind this scenario is to represent a typical day life of a train with a focus on GoA transitions. The target of this scenario is describing how to realize mixed train operations. The first part could represent a RS transfer from a depot to a main station while the last represent a train service to be realized in GoA2 because of trackside constraints. First movement represent a GoA4 transfer to move the train in the station where the first passenger service will start, cab is closed. Here the scenario part realized in GoA4 has the target to demonstrate the smooth transition from/to GoA4.
Main goal	To execute a mission profile which complexity is coming from the presence of GoA changes implying a good coordination between actors and system.
Preconditions	This scenario starts in GoA1 then the unique needed precondition is the train in standstill, nevertheless to ensure a quick test execution is useful to ensure the following additional conditions: train is standstill, in an area equipped with ETCS, its “Train Context State” is “Service Retaining”. Mission Profile and Journey Profile already stored on board. ETCS-OB in SB with valid train position information.
MP	The mission profile contains a sequence of tasks defining requested GoA and reference to JP. The first journey is made in GoA1/2, the second in GoA4, the third in Goa1/2. Only one task to set the train mode is present at the end of GoA4 operations, when GoA1/2

	operations are terminated driver is in charge to set the train in Service Retaining by deactivating the cab. All tasks have a begin trigger set as time and position constraints.
JP	In scenario 2 three different JPs are present: JP0: • Type: RS transfer without passengers • Nid_operational= 0001 • Movement: from St.P N to St.P S (*) JP1: • Type: train service with passengers • Nid_operational= 0002 • Movement: from St.P S to St.P N. JP2: • Type: train service with passengers • Nid_operational= 0003 • Movement: from St.P N to St.P N (1 loop). (*) St.P X is a point within ETCS area but beyond yard. St.P S is a point within South station. St.P N is a point within North station.

Table 19: Scenario 5 Datasheet

Triggered Use Cases	Expected Outcome
13.6.5 Door opening (passenger train)	•At beginning of TJP: ○ as soon as TCG is completed and TJP is ongoing (needs to have ETCS in FS and ADM in AV), ADM can request doors opening. •Intermediate stops and Terminal Station (EoJ): ○ As soon as the St.P is reached
13.6.6 Door closing (passenger train)	•At beginning of TJP and for intermediate stops: ○ When dwell time is elapsed ADM requests doors closing. •At Terminal Station (EoJ): ○ When minimum dwell time is elapsed.
13.4.2 Check departure conditions except signalling 13.4.6 Authorize departure of autonomous train 13.6.4 Supervise departure of a passenger train 13.4.7 Determine stopping point for a freight or passenger train 13.4.8 Traction and brake control 13.4.1 Move autonomous train	Setting of Virtual direction ctrl in neutral When dwell time is elapsed Virtual direction ctrl in forward Train departure Train stopped at the St.P S (EoJ) Note: no Train Doors Operations are executed because of the type of TJP.

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13.4.9 Request holding brake	

Table 20: List of use cases triggered by scenario when tasks TCG and TJP (Type: train service with passengers) are in execution.

5 CONCLUSIONS

The development and validation of standard ATO systems up to GoA3/4 (Grade of Automation) over the European Train Control System (ETCS) is a crucial step toward transforming the European rail system. ATO offers several benefits, including increased capacity, reduced energy consumption, lower operational costs, improved punctuality, and enhanced operational flexibility. The first GoA4 demonstrations are expected to take place in 2026. These advancements allow railways to achieve quick wins without significant infrastructure investments and pave the way for unattended mainline train operations.

The test environment will prove the capability to execute automatically:

- mission profile tasks in nominal mode
- mission profile tasks in degraded mode (such as radio connection loss, train trip/restart mission)
- hand over to remote control operations
- Perform driverless runs
- Execute Journey Profile

And to operate remotely the train for:

- Set the train in service
- Move the train towards mainline from depot
- Move the train towards depot from mainline

The test environment will also investigate the capability to tackle the high-density networks bottlenecks at junctions (especially challenging with freight trains) and the headways around complex nodes.

The WP39 demonstrator will be based on the TEs foreseen for mainline applications (D4: mainline) except TE3, TE5, TE6.1, TE10. These TEs are out of scope and related capabilities will be emulated or not included in the test environment. The scenarios defined for WP39 well represent the railways operation for a mainline service and the configuration flexibility of the assets will permit to this demonstrator reaching the targeted TRL (6-7). Instead, the TEs that will deployed in WP39 follow a more complex track (started by user needs definition and finishing with standard specifications) and consequently the wished TRL is between 5 and 6.

The successful accomplishment of this test will be an intermediate milestone to carry out a test campaign in the framework of the second and third wave of Europe’s Rail on a real line in operation.

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[9] ERTMS Users Group - ERTMS/ATO Glossary, version 1.14, 22/03/2023

[10] ERTMS Users Group – SUBSET 125, version 1.0.0, 05/07/2023

[11] User input for X2Rail-4 Scope Document, version 4, 24/03/2022

[12] FP2-T5_1-D-NSR-124-01; WP5.1 – Documentation of use cases for automating functions

[13] FP2-T5_2-D-FTS-040-02; D5.2 – Definition of Use cases, Operational parameters and Scenarios for Safe Perception Systems

[14] FP2-T5_4-C-MER-011-01; D5.4 – Documentation of use cases for remote driving

[15] FP2-T5_5-D-DBA-007-01 ; Deliverable D5.5 – Documentation of Freight specific user requirements for automation process

[16] FP2-Tauro-X-SNCF-xxx-yy Shift2Rail – IPX - TAURO 1st and 2nd Release package (transfer date 31/05/2023 and 06/02/2023)

[17] SUBSET-139; ATO-OB / ROLLING STOCK FFFIS APPLICATION LAYER; 1.0.0; 05/07/2023

[18] SUBSET-034; Train Interface FIS; 4.0.0; 05/07/2023