Rail to Digital automated up to autonomous train operation

D5.3 – ATO GoA3/4 Specifications review documentation

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The work realized in task 3 is the result of analysis and discussion made during the meetings involving all the Beneficiaries, then the achieved results have been synthesized on a paper base by those partners whose role has been defined as Specificiation/Expert input. At the end, outcomes has been reviewed by all Beneficiaries.

EXECUTIVE SUMMARY

The R2DATO project has the aim to design, develop and demonstrate Digital & Automated (up to Autonomous) Train Operations. To reach this goal, different activity streams have started in December 2022, among which task 5.3 has the responsibility to collect the heritage from precursor projects such as X2Rail-4, TAURO, ARCC and relevant standards such as TSI CCS structuring all the related content in a frame of consistent concepts, architecture and functional needs.

The objective of task 5.3 is to review the available documentation in order to fully investigate the existing proposals (i.e., coming from the above-mentioned projects) and comprehend the underlying rationale behind the choices made. From a timeline perspective, this task has partially overlapped with TAURO project and completely overlapped with X2Rail-4 project. This situation has represented a drawback because the documents were incomplete and particularly not shareable due to their confidentiality level. However, it has also provided a significant opportunity to engage in direct exchanges of opinions, comments and question with the authors.

Task 5.3 activity has started defining the methodology of work to ensure timely and valuable results by exploiting at the best the variety of skills coming from the partners (railway undertakings, infrastructure managers, rail supplier industry, research, and innovation partners), then it has been decided to develop three main themes.

First theme is related to the analysis of architecture and specifications in order to reach a common consensus among basic operational principles: roles and responsibilities of trackside entities under RU and IM control; identification keys to be used at operational level (for addressing journey profile, train data, mission profile); handover between remote driving and automatic operations; basic operations within area with limited trackside capabilities (e.g. depot); freight specific user requirements.

Second theme is meant to highlight the gaps and possible improvements, but also to point to achievements reached taking care of the architecture and concepts realized. The result will avoid repeating the work already done and to give a clear picture of needs and exported constraints to WP3 that is in charge to guarantee the requirements consistency at project level.

The third theme is focused on the relationships between automation processes components and several external technical enablers: Localization, Digital Map, ETCS OB, and Moving Block, all of which are outside the APC cluster.

These themes have been developed progressively and follow-ups were marked during weekly meetings; multiple rounds of both informal and formal reviews, as well as workshops were organized, to ensure that all task partners were aligned with the contribution results.

Due to time constraints for the work package and delays in the delivery of formal inputs from other Flagship Area’s and System Pillar by the defined milestone of M6, the task 5.3 partners at the beginning focused on public documents that were often not aligned with the most recent versions. After the first agreement/input the work has been realized using two different baselines of specifications. Such conditions have required an additional effort to the task. At the time of editing this deliverable, X2Rail-4 tests are still in progress and consequently the expected test results are not yet available, for this reason D5.3 will not take them into account, however it is recommended to use them as input by on-going work packages in the context of the Automation Processes cluster of R2DATO and in the System Pillar.

The comparison of input documentation has revealed that the principles used for defining automatic train operations are almost the same and a good summary of them is available in chapter 7 of ATO SRS up to GoA4 (X2Rail-4 baseline 1 specification [6]). Some misalignment has been identified mainly related to the scope of Remote Driving if it is to be intended as only a fallback solution of GoA3/4 or a technology for a more complex operations like exiting a depot or running on a long distance. In addition to this misalignment, the analysis has determined that among the topics to be deeper developed there are: the interfaces definition (including traceability of variables and functional requirements); better definition of some logics like interaction with ATP, doors management, reverse movement, localization, and the needed exported constraints.

All these results of task 5.3, as detailed in the dedicated chapters of this deliverable, should be taken as a starting point for the development of specifications and functional and non-functional requirements, as mainly intended to be performed in Work Package 6 of R2DATO.

ABBREVIATIONS AND ACRONYMS

In this report, the below abbreviations are used. Each abbreaviation is noted the first time the term is used. Within task 5.3 where possible, terms were adopted from other Shift2Rail project to maintain consistency. The main source used for this alignment is the ERTMS/ATO Glossary [9] and ERTMS/ETCS Glossary of Terms and Abbreviations [8].

AD	ETCS Automatic Driving Mode
ADM	Automatic Driving Module
APC	Automation Processes Cluster
APM	Automatic Processing Module
ARCC	Automated Rail Cargo Consortium
ARS	Automatic Route Setting
ASPM	Automatic Stopping Point Management
ASR	Additional Speed Restriction
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATO-OB	ATO On-board
ATO-TS	ATO Trackside
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
ATSM	Automatic Train Stopping Management
AV	ATO Available
CBG	Centrally controlled area
CBTC	Communication Based Train Control
CCS	Control Command and Signalling
CCTV	Closed Circuit Television
C-ITS	Cooperative Intelligent Transport Systems
CO	ATO Configuration
DE	ATO Disengaging
DM	Digital Map
EG	ATO Engaged
ERTMS	European Rail Traffic Management System
EUG	ERTMS Users Group
FA	Flagship Area
FP	Flagship Project

GA	Grant Agreement
GoA	Grade of Automation
HS	Handshake
HSAck	Handshake Acknowledgement
HSRej	Handshake Rejected
HSReq	Handshake Request
HVAC	Heating, Ventilation, and Air Conditioning
ID	Identity
ISM	Incident Solving Manager
IIS	Infrastructure [Passenger] Information System
JP	Journey Profile
JPAck	Journey Profile Acknowledgement
JPReq	Journey Profile Request
LOC	Localization
LX	Level Crossing
MAWP	Multi-Annual Work Plan
MBSE	Model Based System Engineering
MD	Mission Data
MP	Mission Profile
NA	ATO Not Available
NCBG	Non-centrally controlled area
NP	ATO No Power
OAS	On board Automation System
OCC	Operation Control Centre
OE	Operational Execution
OIS	On-board [Passenger] Information System
ORD	On-board Recording Device
PDIU	Platform Door Interface Unit
PED	Platform Edge Doors
PG	Platform Gates
PIS	Passenger Information System
PSD	Platform Screen Doors
PTI	Platform / Train Interface

R2DATO	Rail to Digital automated up to autonomous train operation
RC	Remote Control
RE	ATO Ready
REP	Repository
RST	Rolling Stock
RU	Railway Undertaking
S2R	Shift2Rail
SCV	Signal ConVerter
SP	System Pillar[1]
SPReq	Segment Profile Request
SRS	System Requirement Specification
SSEM	Supervised Speed Envelope Management
STR	Status Report
TAF	Telematic Applications for Freight (TSI)
TAP	Telematic Applications for Passenger (TSI)
TAS	Trackside Automation System
TAURO	Technologies for the Autonomous Rail Operations
TBL	Traction/Brake Lever
TC	Temporary Constraint
TCMS	Train Control and Monitoring System
TD	Train Data
TDO	Train Door Operation
TE	Technical Enabler
TEN-T	Trans-European Transport Network
TM	Train Management
TMS	Traffic Management System
TP	Timing Point
TPS	Train Preparation Staff
TRL	Technology Readiness Level
TRN	Train Running Number

[1] In the ERTMS / ATO Glossary the abbreviation 'SP' refers to 'Segment Profile'. In the context of WP5, the abbreviation is most often used to refer to 'System Pillar' In this deliverable, the abbreviation refers to 'Segment Profile'. The context in which the abbreviation is mentioned will be uniform enough to provide clarity which of the two terms is used.

TS	Trackside
TSI	Technical Specification for Interoperability
TTSM	Timetable Speed Management
WP	Work package

DEFINITIONS

In this section, a list of definitions is provided to clarify some concepts used in the document.

State Machine: Finite-state machine (FSM) or simply a state machine, is a mathematical model of computation. This model is applied in the design of many devices that perform a predetermined sequence of actions depending on a sequence of events. State machine can be only in one state at any given time, the change from one state to another is called a transition and it happens in response to some inputs. An FSM is defined by a list of its states, its initial state, and the inputs that trigger each transition and for each state a set of available functions are defined.

External Technical Enabler (TE): Technical Enabler outside Automation Processes Cluster (e.g., Localization).

Train inauguration: it is the process to determine train configuration (count, order, direction and capabilities of the consists); it corresponds to train function “Inaugurate train network” as defined in EN15380-4.

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1 INTRODUCTION

The present document is deliverable D5.3 – “ATO GoA3/4 Specifications review documentation”. It is a result of the effort of all involved partners in task 5.3 “Review of specification for ATO GoA3-4 technology” within work package 5, as part of the Automation Processes Cluster of ERJU FP2 “R2DATO”.

The Automation Processes Cluster (APC) has the mission of architecting and developing Automation Processes through different Technical Enablers (TEs) – Automating Functions, Perception, ATO Technology and Remote Driving. The first step to reach this objective consists in defining the user perspective giving a description of the railway system as-is and the wished future state, therefore it is important to start with a conscious knowledge of the state of the art to realize valuable use cases and operational scenarios.

Within work package 5 *“Automation Processes Use Cases and user requirements”,* there are six tasks working in parallel to achieve this common goal of reviewing ATO GoA3-4 specifications and delivering use cases as well as user requirements. These will be used as a starting point for the further specification, development, prototyping and eventually demonstration of the TEs in the Automation Processes Cluster. WP5 activities have been organized on six main work areas that are:

- task 5.1 Definition of use cases, operational parameters, and scenarios for automating functions
- task 5.2 Definition of use cases, operational parameters, and scenarios for safe perception systems
- task 5.3 Review of specification for ATO GoA3-4 technology
- task 5.4 Definition of use cases, operational parameters, and scenarios for remote driving
- task 5.5 Definition of freight specific user requirements
- task 5.6 Definition of urban light rail use cases and operational rules

It is known that the major interests of the railway market are to improve capacity, punctuality and increase energy efficiency. Under this commitment in the last years many efforts have been focused on defining a solution for train operation with no driver (Driverless/GoA3) and no human assistance (Unattended/GoA4) while train is in daily service. Now the sector is aware of the need to evolve the railway system by redesigning procedures and interfaces, both internally within the on-board subsystem and externally for the wayside part. Over the last years several activities and projects has been realized on this topic and for this reason is now important to make a rational analysis of the documentation available and make new progress exploiting at the best the work done so far.

The work of WP5, task 5.3 has taken in charge the documentation released by Shift2Rail – more specifically from the deliverables of X2Rail-4 and TAURO projects making an analysis, from one side meant to highlight the gaps and possible improvements, but also to point the achievements reached taking care of the architecture and concepts realized. The objective is to avoid repeating the work already done and to give a clear picture of needs and exported constraints to WP3 that is in charge to guarantee the requirements consistency at project level.

Deliverable 5.3 is an important basis for the development of APC TEs and other external TEs contributing to define the future railway system. It provides a kind of guideline suggesting those functional areas that needs to be strengthened and those that instead are well consolidated for

realizing the Europe's Rail vision in Automation Processes. The work of task 5.3 will be further utilized and developed in multiple Work Packages, including but not limited to:

- WP6 Automation Processes Specifications: The objective of the tasks under WP6 is to derive a set of non-functional and functional requirements for automating functions, and to define architecture and interfaces for automating functions in passenger and freight application. It is intended to use the operational scenarios and use cases as a starting point.
- WP7 GoA3/4 Data Factory Specifications and Implementation: WP7 may benefit from the operational scenarios to refine the data factory requirements.
- WP8 Safety Analysis and Risk Assessment: The objective of the task under WP8 is to cover the Hazard identification, Safety Management Report and Hazard Log for Automating Functions.
- WP9, WP10, WP11, WP 12 Prototype development.
- Demonstrator Cluster: the Work Packages in the demonstrator cluster may use the operational scenarios and use cases as a basis for their test and validation scenarios.

Deliverable 5.3 has been organized as described in the following list:

- Chapter 1 gives an overview of task 5.3 activities, positioning its contributions in the framework of WP5 and inside R2DATO. In addition, it describes the adopted methodology, objectives and remaining open points.
- Chapter 2 contains the results of analysis and review made on input documents. Here are listed the documents that have been taken as input, the consolidated principles to be maintained in the context of R2DATO, and the functional and architectural topics that need to be strengthened.
- Chapter 3 is mainly a reference to the results of other WP5 tasks giving an overview of the most important use cases under the responsibility of TE ATO technology. The objective is to describe impacts on components, functions and architecture in order to fulfil the capabilities needed during a 'Day In The Life Of' a train.
- Chapter 4 aims to contextualize the X2Rail-4 ATO SRS up to GoA4 specifications by highlighting the expectation in terms of functionalities from other components belonging to the railway system.
- Chapter 5 describes the relationship between R2DATO and other projects of Europe's Rail, outlining the use cases where different Technical Enablers can interact together.
- Conclusions and open points are summarized in chapter 6, followed by references.

1.1 DEVELOPMENT METHODOLOGY

The methodology applied to realize task objectives including the present deliverable has been formalized in the Deliverable Development Plan [1] it includes time schedule, activities portioning between partners and review process. The progress, as well as unexpected issues, have been regularly monitored through weekly meetings.

1.1.1 Deliverable objectives

This deliverable is the result of requests contained in the description of task 5.3 included in the 'Grant Agreement' (GA) at page 29 and shown below.

> Review of specification for ATO GoA3-4 technology
>
> Based on existing specifications delivered by Shift2Rail X2Rail-4 project, several activities must continue for their completeness and enhancement.
>
> To support a collaboration with the other clusters, this task is in charge to document needs and exported constraints included in the "up to GoA4" specification issued by X2Rail-4.
>
> This task analyses innovative products and services developed in the context of the various FAs and in next evolution of CCS, the aim is to evaluate the impacts to be included in DATO system in order to guarantee compatibility and exploitation of these new technologies (e.g., signalling based on moving block). Inputs from System Pillar and Innovation Pillar will be considered until M6 (MS1 – Consolidation of external inputs milestone).
>
> Considering those input documents, the interaction with other FAs (in particular FA1) and coordination with the other TEs (in particular TE-01, TE-06, TE-07), this activity is in charge to review/enhance:
>
> • Operational requirements and use cases (including degraded or failure mode) in the various railway sectors (mainline, regional lines, shunting yard, stabling and freight applications) affecting on ATO-AV and APM components.
>
> • X2Rail-4 test outcomes review and further development of the behaviour of each functional requirement (state
>
> machine).
>
> Concerning freight trains, gaps of the system architecture must be identified, leading to the definition of concepts for flexible and configurable system solution in case harmonisation of operational rules is not achievable.

The objectives have been then synthetized as:

- General review of operational requirements defined in the input documents (chapter 2).
- Identification of use cases affecting ATO-AV and APM (chapter 3).
- Definition of needs and exported constrains (chapter 4).
- Analysis of interactions with external flagship areas (chapter 5).

1.1.2 Limitations and open points

The main limitation faced by task 5.3 has been related to the collection of input documents. Despite the deadline specified in the GA (M6 June 2023), no input has been received from the SP and other FPs.
For this reason, the work realized has been conducted only using the available documents.

2 EXISTING AND RELEVANT DELIVERABLES FROM PARTNER PROJECTS

To develop the Next Generation ATC and to deliver scalable automation in train operations efficiently in terms of efforts and time it is mandatory to make a smooth handover of the activities carried out by previous EU-funded initiatives X2Rail-4 and TAURO projects. In practical terms, it means to analyse and compare the work done in these two streams, focusing on checking the consistency of contents, making a critical study of assumptions and architecture, and identifying the parts that need to be enhanced.

Starting from the collaboration map of Automation Process cluster (R2DATO WP4 “Automation Processes System View”) the list of TAURO documents to be used as input for task 5.3 has been created (see Table 1). This list basically refers to documents directly related to ATO technology and documents related to the design of system architecture. Therefore, deliverables related to specific technologies (as sensors for obstacle detection) has been marked as out of scope.

WP	Code	Title/Content	Type	Status	Transfer Date
WP2	TAU-T2_1-D-CAF-004-08	D2.1 - Specification of the remote driving and command	Deliverable	Final	06/02/2023
WP3	TAU-T3_1-D-FTI-039-02	D3.1 - Contribution to enhanced TCMS for automatic monitoring functionality regarding autonomous train	Deliverable	Final	06/02/2023
WP3	TAU-T3_2-D-FTI-025-02	D3.2 - Contribution to enhanced TCMS for automatic diagnostic functionality regarding autonomous train	Deliverable	Final	31/05/2023
WP1	TAU-T1_4-D-KNR-007-01	T1.4 - AI Enhanced Diagnostic Use Case	Report	Draft	06/02/2023
WP1	TAU-T1_4-D-FTI-014-01	D1.4 - Applicability studies of environmental perception system	Deliverable	Final	31/05/2023
WP1	TAU-T1_6-D-BTW-001-03	D1.6 - Development of a system demonstrator and long-term assessment for the indoor environment perception system	Deliverable	Final	31/05/2023

Table 1: TAURO background for APC

As well-explained in [2], WP5 task 5.3 timeline is fully overlapped with X2Rail-4. Therefore, the review activity has been realized after having agreed a collaboration plan between the two projects. The first delivery called “X2RAIL-4 BASELINE 0 SPECIFICATIONS FOR THE ATO GoA3/4” has

been provided on 05/05/2023 ([3], [4], [5], [7]). A second delivery called "X2RAIL-4 BASELINE 1 SPECIFICATIONS FOR THE ATO GoA3/4" has been provided on 23/06/2023 (see Table 2).

Release	Document Family	Title	Notes
X2RAIL-4 BASELINE 0	ATO (up to GoA4) Operational Concept	ERTMS/ATO Operational Principles	This document has been updated to align with GoA3/4 and Version 1.9 has been released in the X2Rail-4 ATO Baseline 0.
	ATO (up to GoA4) Specification	SRS 0.2.4	Logical Architecture Specification up to GoA4 release 20230418
		SRS 0.2.4 Appendix A	Interface Definition
		SRS 0.2.4 Capella model	MBSE model to be imported in the tool Capella 5.0.0 via File/Open Projects/Archive menu (zip file)
X2RAIL-4 BASELINE 1	01 - ATO GoA2 Specification	Documents submitted to be part of the TSI 2023	SUBSET-125; SUBSET-126; SUBSET-130; SUBSET-139; SUBSET-143
		Concept paper dedicated to the adhesion management	The concept paper related to adhesion management outlines the concept for adhesion management within the ATO system.
		The application guide for ATO in GoA2	The application guide for ATO in GoA2 provides guidance for application/project specific implementation of ATO. It addresses the blending of brakes, gives recommendations on the data quality and recommendations for certain engineering tasks.
		The ATO-TS/TMS interface specification	The ATO-TS/TMS interface specification defines the data transmission between the ATO-TS and the TMS to support ERTMS/ATO.
		The ATO Operational Performances requirements	The ATO Operational Performances requirements specifies requirements for the ATO that are related to performance and not already covered by the other documents of the Operational Concept.

	02 - ATO (up to GoA4) Operational Concept	ERTMS/ATO Operational Principles	This document has been updated to align with GoA3/4 and Version 1.9 has been released in the X2Rail-4 ATO Baseline 0.
		ERTMS/ATO Operational Principles – Open points	This Appendix document lists the open points from SNCF based on the Operational Principles Version 1.8. These open points could not be covered by the Version 1.9 and Version 1.10.
		ERTMS/ATO Operational Requirements	This document is not yet updated to align with GoA3/4 needs.
		ERTMS/ATO Operational Scenarios	This version includes only the operational scenarios for GoA1 and GoA2.
		ERTMS/ATO Operational Scenarios	This version includes operational scenarios (Regular and Non-regular) for all GoA1-4. This document also provides: Scenarios template; Scenarios examples (Automatic train wake-up; Compose train; GoA transitions)
		ERTMS/ATO Operational Scenarios - Crosscheck list	Appendix to the ERTMS/ATO Operational Scenarios Version 1.12. This document crosschecks the operational scenarios with the SRS Version 0.2.4 Use Cases and the SNCF-DB Non-regular scenario analysis.
		ERTMS/ATO Glossary	This document is not updated to align with GoA3/4.
	03 - ATO (up to GoA4) Specification	SRS 0.3.0	Logical Architecture Specification up to GoA4 release 20230620
		SRS 0.3.0 Appendix A	Interface Definition
		SRS 0.3.0 Capella model	MBSE model to be imported in the tool Capella 5.0.0 via File/Open Projects/Archive menu (zip file)
	04 - ATO (up to GoA4) Safety Assessment	ATO (up to GoA4) Safety assessment	X2R-4 hazard identification

Table 2: X2Rail-4 baseline 0.1

Additional input considered by this task was:

- TSI CCS 2023 and relevant ATO subsets (informal drafts and 10/08/2023 release)
- Shift2Rail - IP5 - ARCC Demonstrator – Deliverable 1.7 “Documentation and evaluation of GoA2 freight demonstrator test results in specified testing scenarios, proposal of next steps” (downloaded from project website 30/01/2023)[2]

2.1 CONSISTENCY CHECK OF CONTENTS

The available documentation coming from the input projects face the topic of automatic train operation from different point of view and with different specification approach. The review analysis of task 5.3 has detected a good level of consistency showing links among capabilities, functions, entities hosting these functions and their related exchanges, even if it is expressed at different layers of the design methodology (MBSE approach). It means that the user needs, normally modelled with “Operational Capabilities” in the form of use cases, correspond to the “Capabilities” in the Logical Architecture layer.

The consistency check focused on the content related to on-board systems; therefore, some specific functions described and allocated to trackside have just been noted to understand their possible on-board impacts (e.g., passengers flow estimation and update of timetable Wayside Perception System).

The content developed by the projects is related to topics that are not overlapping: in fact, while X2Rail-4 provides the GoA4 system design with high level functions description, decoupling from specific rolling stocks capabilities (external actor) or specific technologies, TAURO investigates specific contexts as:

- Use case definition aimed to involve artificial intelligence and environment perception technologies in railway operations as shunting/stabling, railways environment detection, train faults detection, traffic/train management.
- Indoor environment perception system able to catch events inside the vehicle and minimize/ avoid disturbance on the vehicle operation and the passenger’s travel experience or freight’s service quality.
- Use case definition of remote driving and command showing the needs and actors interactions requested to realize remotely the rolling stock functions under ETCS and in shunting yard.
- Monitoring of rolling stock sub-systems diagnosis and testing activities at the start and during the mission. Sub-systems functionalities have been analysed, in the scope of GoA4, defining impact to the running capability and to the safety; reactions in case of failure are also proposed in order to continue the run also by describing new/updated functions.

[2] While no formal input was received from ARCC before M6, the involvement of DB Cargo in both projects meant the results could be included informally in task 5.5.

As stated before, the harmonization of the documents is demonstrated by:

- the use of a Mission Profile concept
- the same approach for detecting wayside anomalies (obstacles, humans, animals, fire, level crossing, catenary anomalies, track anomalies, track signals)
- Landmark detection in TAURO and in X2Rail-4
- Lineside Signal aspect reading to identify a signal aspect by a dedicated component (SCV).
- Remote driving aligned with the concept of X2Rail-4, in particular:
    - Concerning ETCS: the usage in context where ETCS mode is SR or SH and the use of remote data entry procedure.
    - Concerning operation: the activation of specific TCMS mode where additional speed limits are observed.
    - Concerning architecture:
        - the assumption to segregate sensors between perception and remote driving.
        - the assumption the RU knows the train position by LOC (same assumption external constraints for REP/LOC/RU)

Nevertheless, there are some minor divergencies that should be solved in the next design phase of R2DATO (WP6):

- In some cases, the adopted terminology is not the same (for example, the term “wayside” is often used to indicate lateral signalling); also actors have different names in some cases.
- The role of "train management" as defined in S2R encompassed RC centre & RC operator actors (TAURO actors in UC3.1.0.1).
- The following functionalities are treated in different ways:
    - Specific functionalities like “activation of surveillance system” are not considered in X2Rail-4 because they depend on the capabilities available in the rolling stock. In X2Rail-4, energy-optimized driving is tailored by each supplier without specifying any specific technology.
    - Wayside detection made at trackside level, while in X2Rail-4 this is not present.
    - Remote Driving to be used for ETCS failures.
    - Transfer from depot to station: Use case defined in TAURO and part of WP5.4 but excluded in S2R SRS 7.10.1.1.6. The remote driving shall permit to drive the train until a stopping point where a driver is available to continue in a lower GoA level or where maintenance is possible without affecting traffic operation. It is not foreseen to exit a depot or for running on a long distance.

- Driver (onboard and remote) shall interface with Operational manager for TAURO (see UC.3.1.2) while the X2Rail-4 model does not include an interface.

2.2 VALIDATION OF THE BASIC CONCEPTS

The work on input specifications has been addressed to recognize what are the basic principles used to realize GoA4 specifications. Such principles have been reviewed to understand if they are still valid. Almost all principles have been accepted, and the list of the most important principles is presented in the following sections.

2.2.1 Trackside data

The automatic train can be realized only on the base of solid data describing all the aspects of its operation. The rational partitioning of data, taking into account aspects as functional applicability, ownership and safety, has produced four different data sets. Some of these concepts were already introduced in the TSI 2023 (Journey Profile and Segment Profile, see [10]), while others are new, like Mission Profile and Train Data. Trackside Data need to be referenced in order to allow the right association between the operational and physical context. For this reason, four keys for accessing these databases have been identified: path number (Reference TRID), Segment Profile ID, Consist ID and Train ID.

2.2.2 Rolling stock and ATO on-board components

The current assumption, present both in TAURO and X2Rail-4, is to allocate the monitoring and the management of Rolling Stock components or features at the level of Rolling Stock, since too much is dependent on train architecture and adopted technical solution, while actions and restrictions are managed at APM level. In X2Rail-4 with cooperation of CONNECTA team, the specification of a TCMS interface is in progress following a functional approach which should be independent from the technologies and layouts, capabilities and functions of a particular train type used at the Rolling Stock level.

The interface shall provide to ATO on-board components (APM) about a problem at Rolling Stock level giving the restrictions imposed due to this problem (e.g., immediate stop applied; operation permitted during a limited period/distance and/or under some speed restriction/power consumption).

The TCMS is in charge to manage the train unit as a whole, taking care of all subsystems distributed along it whatever is the composition (loco haul train, multiple consists etc.). Coupling and splitting are operations assisted by ATO as scheduled in the mission profile, but the final train inauguration is still allocated to TCMS as well as the distribution along the train of its functionalities (e.g. doors opening, cooling/heating etc.). The resulting Train Unit (coupling of consists) shall be equipped with compatible TCMS versions.

2.2.3 Interactions between ATO on-board components and actors

Even though a lot of effort is focused on automating functions, an important concept is related to the interaction between the ATO system and human actors in charge of performing specific tasks. This element is crucial above all to facilitate the migration of railway system towards GoA4 operations. It has been developed by defining boundary in terms of time and location during which a hand-over process guarantees a clear split of responsibilities. In the mission profile, a task shall be allocated

for this type of activities and the execution will be granted only under the fulfilment of conditions that ensure the realization of the process safely and without deadlock.

Another important type of interaction is the one with the ATP. This interaction is independent of the ATP state (taking into account that train awakening is managed by RU). The only constraint is that ATP supervision is required to allow any GoA level. Train Preparation activities, including ATP data entry (e.g. SB state), belong to a context where any GoA level is applicable, then train preparation activities shall be managed by the system under one of the possible GoA levels (Manual/Semi-Automatic->GoA1 or GoA3, Automatic->GoA4). Nevertheless, it is important to highlight that the full set of GoA4 functionalities are granted under a reasonable degree of ATP supervision, for example in SR are not foreseen GoA4 movements of the train (to be covered by remote driving), this concept is the same already applied in TSI CCS 2023 (where GoA2 automatic driving is allowed only if ETCS is in AD mode). Such assumption is consistent with the current ATO specifications (TSI 2023) and provides a bigger reliability of the system: the knowledge of a safe route allows to take the right decision regarding the output of environmental perception (discrimination between obstacles and objects).

2.3 VALIDATION OF THE ARCHITECTURE

The architecture of X2Rail-4 has been taken as reference and compared with the concepts use case and specifications of the other projects. In general, the architecture is valid and needs only to be supplemented to take into account the Remote Driving, the same applies to interfaces definition including also the data structure of mission profile.

An important update will be needed on the interface definition between TCMS and ATO on-board components, currently it is designed only for GoA2 operations (see [6]) and a definition is requested to allow future demonstration at higher GoA levels and Remote Driving. It is proposed to start with the basic needs as control the cab and other components (lights, pantograph, horn), and later to continue with adding other standard exchanges to control or monitor train functionalities independently from the technologies used at the Rolling Stock level.

The current PER component should be split in a PER-Obstacle and an optional PER-Signal. Most likely PER-Signal would need to use specific sensors for signal aspect detection in addition functions related to SCV are independent from APM functions. If the PER module is split into one for SCV and one for APM (interfaces should be duplicated) at logical level, any supplier is still able to propose a physical architecture where these components are merged. PER functions are meant for Automatic Train Operations up to GoA4 and they have to be kept separated from other imaging acquisition functions dedicated to remote driving. This architectural choice allows ensuring Remote Driving back-up in case of PER failure.

The architecture does not propose a clear boundary between Localization ATP and ATO ON-BOARD components. Even if the intention to have a central system responsible for train localization is evident, ATP interfaces still provide localization data, in some cases this represents an overlap

(e.g., in the safe positioning of the train front end) with unknown effects on overall system performances.

This architecture has different impacts on existing systems (mainly ATP, but also ATO-OB GoA2). These modifications have been introduced for realizing operational needs and to design a clean system limiting the number of interfaces and allocating the functions to the right components. Nevertheless, it is requested to make a second analysis of new use. Obstacle End of Authority is an example: On the one hand, the current solution ensures safety and avoids immediate intervention when the obstacle does not impact the braking curve, but consideration of a large confidence interval may affect the effectiveness of this principle. On the other hand, a proposal of having a service brake application through APM or ADM avoids spurious Emergency Brake intervention in case of false alarm but could stop the train too early.

2.4 POINTS NOT ADDRESSED OR PARTIALLY SPECIFIED

The documents received as input have been processed to understand the current design of ATO up to GoA4. The work done so far follows specific guidelines coming from grant agreements and operational principles. In the last years, new capabilities have been requested from different stakeholders and such open points have been traced in the document [11]. Some of them have already been addressed, while others are listed here. It is important to advise that a final baseline of documents will be delivered by December 2023. Then it is expected that some open points will be closed and part of the information contained in this section is not valid anymore. Nevertheless, it represents a useful checklist to use for addressing the next design activities.

2.4.1 Interfaces

In Appendix A of baseline 0.1 the following interfaces does not contain packet definition:

C55 (APM-TCMS);

C63 (APM-OMTS);

C65 (APM-ORD);

C22 (REP-ADM);

C26 (REP-LOC);

C19 (REP-ISM);

C34 (REP-DM);

C14 (REP-OE);

C1 (REP-MD);

C24 (REP-TD).

In addition, it is necessary to have a traceability matrix for all interfaces that links each exchanged variable with its corresponding functional requirements.

2.4.2 Trackside communication principles

The requirements that define the interaction between on-board and trackside are well specified, but they seem to fit the basic case where two transactors are realizing the interface with the REPOSITORY. However, since the architecture allows different configurations, such as having dedicated components that provide only one service (e.g., only Train Data), it is necessary to verify consistency of these communication principles.

2.4.3 Train compositions

The current specifications account for different train compositions, but the related requirements do not exhaustively cover the management of intricate compositions that include multiple instances of ATP, TCMS, and ATO components. For example, the proposal to send a sleeping signal from ATP in such cases needs to be further investigated, as it is not supported in the current ETCS specification (where the sleeping signal is an input to ATP).

2.4.4 ETCS-OB and GoA4 operations

As mentioned in chapter 2.2, the ETCS-OB is a crucial actor in its interaction with ATO up to GoA4 components. These interactions belong to two levels: the first level collects all the exchanges required for train preparation that is the ETCS data entry; the second level involves exchanges needed for the execution of train operations under ATP supervision.

2.4.4.1 DATA ENTRY

The current solution of data entry is based on a mechanism of error detection by requiring the input from two independent sources: TCMS is the on-board source of ETCS train data, and a trackside repository called Train Data is the second source. While for trains with a fixed formation (or a finite number of predefined compositions) it is feasible to allocate on TCMS the role of on-board train data repository, in the case of trains with variable formation the feasibility depends exclusively on the deployment of DAC. It remains the responsibility of the RUs to define which type of data entry (fixed or flexible) best fit its ETCS-OB equipped vehicles. Without DACs, a specific task must be defined in the Mission Profile (MP) for intervention of Train Preparation Staff. The process of data entry, but also the loss of train data validity or data entry rejection, is distributed among different components (TCMS, ETCS-OB, APM, REP), requiring a high degree of synchronization. The design team is responsible for providing detailed specifications regarding logic behaviour, triggering conditions, and guaranteeing validity of state machines.

2.4.4.2 SIGNALLING INFORMATION

For the train operation up to GoA4 the movement of the train is modulated by APM on the base of information received from PERCEPTION. An obstacle then will be managed as an additional obstacle End of Authority and an On Sight movement will be supervised by means of additional speed restriction depending on PERCEPTION capability. However, the consideration of a potential large confidence interval may anyhow lead to an immediate Emergency Brake, from one side, the current solution ensures safety and in one case avoids immediate intervention when the obstacle does not impact the braking curve in the other case ensure the train stop as soon as an anomaly is detected inside the detectable area. From the other side, could be interesting to investigate alternative solutions excluding ETCS-OB involvement and by allowing APM or ADM to request directly to TCMS a service brake application taking into consideration the possible side effects deriving from an architecture where multiple sources have access to brake function.

2.4.4.3 REMOTE DRIVING

The role of ETCS when the remote driving/control mode is active still needs to be fully investigated. Currently, there are use cases (mainly in emergency situations) that involve bypassing the ATP, while others involve performing remote driving actions under the supervision of ATP. Therefore, it is crucial that the interactions among remote driving-related subsystems, TCMS and ATP are consolidated and specified.

2.4.5 LOCATION PRINCIPLES, TRAIN POSITION AND TRAIN ORIENTATION

ERTMS/ATO TSI 2023 specifications define ATO train position using ETCS-OB data. This approach, in the context of a new railway system where train position and orientation are completely allocated to a dedicated component, needs to be reanalysed: all functions concerned by train position/orientation shall use LOCALIZATION data.

2.4.6 On Board Staff/Train Preparation Staff/Driver

In the current solution, the function in charge of managing the interactions between all human actors and the system is partially described. It is necessary to specify how the system can monitor the task execution made by a human being (clean worker, catering, technical staff etc.; due to the human nature is not possible to use time limits) and how the system can detect the acknowledgement of a specific role being taken over (driver, train attendant).

2.4.7 Doors management

Already in GoA2 the automatic operations of the doors are foreseen. This function in the GoA4 system is enhanced to also manage incidents. The specifications define a function which behaviour depends on three systems ADM, APM and TCMS, requiring a degree of synchronization that the design team has to specify in detail explaining logic behaviour, triggering conditions and ensuring validity of state machines.

2.4.8 Repository

The GoA4 specification proposes to allocate the functionality to collect trackside data required by on board components to perform train operation (except ETCS-OB) to a single component. REPOSITORY acts like a service provider answering to the need of various on-board users with the advantage to be the unique logic system interacting with trackside reducing conflicts, discrepancies and exported constraints. The data structure has only been drafted using the concept of layers dedicated to each user. However, requirements are missing related to the strategy of collecting data from trackside, in order to avoid it becoming a bottleneck for the most demanding consumer.

2.4.9 Reverse Movement

A specification is missing describing system behaviour in case a reverse movement is needed (e.g., overshooting, see UC5.1-017).

2.4.10 Localization

The role of this component has an important impact on the overall system, but an activity to express all the capabilities requested by ATO up to GoA4 is still missing. In details is not specified how to realize the synchronization between components; few functional and performance requirements are requested (e.g., the need to know orientation and position after wake up). Missing interface definition with REP to realize localization inside SP/JP.

2.4.11 GoA level

The GoA level represents an overall system state, independent from the state of a single component, in charge of defining who is responsible for the train operations. In the documents analysed, the functional requirements describing how to define the GoA level are missing. In addition, it is important to specify the actors involved in the request of the desired GoA level, defining the behaviour of the system based on their iterations (for example, the actions to be taken in the event of inconsistent GoA level requests).

2.4.12 Freight train applicability

X2Rail-4 SRS up to GoA4 defines an architecture and functional requirements that support train automation in all railway application sectors, no critic gaps have been detected. The specific Freight trains needs are mainly allocatable on TCMS and ADM.

TCMS, as stated in 2.2.2, is responsible for the control and management of all subsystems distributed along the train, including DACs if present. Depending on the presence of DACs, train preparation could be realized automatically or otherwise by means of specific tasks allocated to TPS.

ADM is the component responsible for automatic driving which behaviour shall be adapted to the type of train. The input requested by ADM to operate/drive the train correctly shall be transmitted to on-board as already foreseen by specifications. In addition, ERTMS/ATO TSI CCS 2023 already defines requirements for Traction / Brake Control encompassing all railway applications.

Specific freight operations are the ones realized in shunting yards (railroad facilities at some freight train terminals, used to divide and sort wagons onto different tracks) and a detailed description is provided by use cases of TAURO deliverable D1.4 (see [16]). In addition, Task 5.5 ([15]) and FP5 Trans4m-R are working to define the related specification.

3 IDENTIFICATION OF THE RELEVANT UCS FOR THE SYSTEM PRINCIPLES AND RELATIONSHIP WITH TECHNICAL ENABLERS

ATO TE is responsible of supervising the mission execution, driving the train in different grades of automation and applying operational rules in case of incidents by using the capabilities of different TEs (perception, remote driving, automatic functions) and other TEs such as digital map or localization under the supervision of ATP.

In the following sections, a first analysis is reported of the UCs that are already specified within S2R context and in other R2DATO WP5 tasks. These UCs are identified as the most relevant ones, as they further complement the already consolidated use cases in the GoA2 level and will have the greatest impact in the subsequent design stages planned in R2DATO.

In the following sections, the relevant use cases are written in italic style, the detailed descriptions are available in [12], [13], [14], [15].

3.1 MISSION ELABORATION

UC5.4

S2R mission profile definition does not integrate remote operation. The UCs define the use of remote driving not only for degraded situation (fallback) but also for nominal operation with handover between different masters and with the capability to unlock situation in GoA4.

➔ Mission profile to include handover task with remote driver.

3.2 MASTERSHIP

UC5.4.Mastership-22 UC5.4.Mastership-20

ATO technology together with ATP and TCMS will have to manage handover between different train users/masters and integrate the remote driving with possible limited maximum operational speed.

Impact on:

- the mission definition (e.g., mission could encompass tasks to be executed either in remote driving in GoA2 or in GoA4);
- the supervision of the mission execution when remote driving is the master;
- the state machine to integrate remote driving.

3.3 TRAIN PREPARATION

UC5.1-001 UC5.1-002 UC5.1-003 UC5.1-004 UC5.1-007

ATO TE supervises the train preparation when operating in GoA4. The dispatching of the preparation tasks (collection of data, train wake up, put the train in service, brake test etc.) between Automatic Functions TE and ATO TE may request modification in the current S2R functional allocation.

UC5.1-007 UC5.4

Remote operation could be used to perform few tasks during the train preparation (e.g., data entry).

This will clearly impact the mission profile definition and the ATO TE capability to supervise remote operation and consider remote tasks.

Relationship with TEs

During train preparation the cab selection could be realized only if train orientation and travelling direction are known. TEs involved: LOC, DM, OE (ATP excluded see 2.4.5).

3.4 MOVE A TRAIN

Relationship with TEs

All train movements can be realized if train position/orientation and Journey Profile are known. TEs involved: LOC, DM, OE.

3.4.1 Move a train within depot/stabling area

UC 5.2-0057: Drive inside depot / stabling or maintenance facility

- ➔ This UC defines automatic train operation in depot/stabling area under a virtualized ETCS L1 (reported in UC as "ATO over Lateral Signalling" ETCS compatible), implying the elaboration of a dedicated journey profile to be executed onboard. It could possibly impact ATO TE on: Specific stopping point for depot to integrate in the digital map;
- ➔ Journey features: timetable may be not relevant for movement in depot;
- ➔ Collect Mission data and manage tasks listed in Mission Profile.

UC5.1-007: Prepare train for departure

Remote driving use cases describe train operations mixing remote driving, manual driving and automatic driving. It may impact the mission profile as defined in S2R and the mission supervision.

3.4.2 Move a train with respect to a journey

UC5.1-015: Skip station by passenger service

In case of emergency, it may be possible to stop the train to an unplanned stop. It can have an impact on the mission supervision by ATO TE and the possibility to cancel "station skip".

UC5.1-042: Handle fire accident on passenger train – running

As for the previous use case, the journey can be modified or cancelled due to an emergency such as a fire onboard, requesting to stop the train in a safe area (rescue place) as soon as possible.

Relationship with TEs

Degraded situation implies involvement of ATP.

3.5.1 Adapt driving to incident train related

UC5.1-040: Manage fire on-board locomotive or empty passenger train

UC5.1-041: Handle fire accident on passenger train - in station (at standstill)

UC5.1-042: Handle fire accident on passenger train - running

UC5.1-047: Handle infrastructure restrictions ordered by authorities - Bomb alarm on train

UC5.1-048: Handle stop train unit due to security incidents on-board - Identification of personal details

UC5.1-071: Restricting train operations due to unauthorized escape door opening (in tunnel)

These use cases of D5.1 have to be deployed in the design of ATO TE taking into account the principle ruling the interactions between ROLLING STOCK and ATO ON-BOARD COMPONENTS (see section 2.2.2) based on paradigm “detection+limitation”/”restriction execution”.

3.5.2 Adapt driving to incident

Most of the WP5.2 UCs deal with incident management from the detection to the application of the relevant reactions relying on the operations rules.

The relationship between TE PER and TE ATO becomes obvious. Hereafter, examples are listed of UCs that may impact S2R ATO TE capabilities:

UC 5.2-0019: React to obstacle

ATO technology may adapt the way to react to an obstacle depending on the type of object detected and evaluated by PER TE:

- ➔ Emergency brake;
- ➔ Speed reduction;
- ➔ Horn request;
- ➔ Lower the pantographs.

UC5.2.0020 FireOnEmbankment

In case of fire, it may be requested to change the running direction to move away from the danger. The change of running direction may not be triggered by any journey profile update. Impact on select driving direction, journey profile execution.

The strategy of driving in the fire area depends on the fire context. The capacity of ATO TE to adapt the driving can be impacted by these uses cases:

- Apply reduced speed approaching the fire area;
- Stop the train in appropriate emergency area;

- Cross the fire area.

3.5.3 Management of passengers

UC5.1-041: Handle fire accident on passenger train - in station (at standstill)

UC5.1-042: Handle fire accident on passenger train - running

Incidents request to manage the passengers by informing them about the situation and in some emergency cases to organize the rescue and evacuate them to a safe place. ATO TE capability to evaluate the situation and take the appropriate measures may be impacted by these UCs.

3.5.4 Management of GoA4 components failure

UC5.4-038: Take responsibility after some degraded PER in GoA4 mode by remote control driver

Remote control is used to take over the train in case of failure of one of the ATO up to GoA4 functionalities. Depending on the failure, ATO TE may still need to operate such as to stop the train in a safe area (see PER failure UC) or to give a remote driver the possibility to engage GOA2 driving (PER failure UC).

Possible impact on the mission execution/supervision.

4 NEEDS AND EXPORTED CONSTRAINTS

The activity realized by X2Rail-4 has also been based on assumptions related to functionalities provided by external systems. Task 5.3 has performed the collection of all these exported constraints providing a clustering based on component/function allocation.

The Table 3 represents the outcome of this activity, whose main use in the context of R2DATO will be to ensure that all the design WPs (specifically, WP6 for APC cluster and other design WP related to external Technical Enablers) can take into account these requests. Additionally, WP3 and the System Pillar are responsible of guaranteeing consistency throughout the project. It is important to advise that a final baseline of specifications will be delivered by X2Rail-4 in December 2023, then the information of Table 3 will need a consistency check with respect to the new release.

X2Rail-4 SRS up to GoA4 exported constraints are mainly allocated to ATP and to TCMS. In both cases many requirements are functionalities already included and specified for these systems. For the others, a synthetic description is provided for each cluster:

- ATP: supervision of the train taking also into account APM information (from obstacle detection or other train incident detector), automatic data entry; ATO vitality monitor, provide LRBG and LX information; basic interaction to recover FS mode.
- DM: definition of type of data needed for enabling automatic train operations, in some cases as updating of SS126 (SP and JP concepts), in other cases as new data definitions (as for example railways asset description with geographical references).
- ISM: Incident Solving Manager is a component in charge to manage deviations from nominal mission by European instructions, it manages also non regular situations as passenger flow in crowded situation (authorization for door). A dedicated interface links ISM and ATO up to GoA4.
- LOC: Localization provides time, position and orientation of the train; it is also connected to PERCEPTION for landmark detection. As expressed in chapter 2.4, these exported constraints need to be enhanced, regarding data content specification and performance and safety requirements.
- MD: new component in charge to manage Mission Profile.
- OE: new component in charge to manage Journey Profile, concept already introduced with TSI 2023 [10].
- RAILWAYS ASSET: It is requested that railways asset ensure a minimum level of capabilities that are fundamental to keep under control the complexity of ATO up to GoA4 system. For a better understanding, an example is the assumption that thanks to the good quality of the rail (as is the case in Europe) there is no need to allocate functions to analyse the geometry of the line for detecting anomalies (broken rail, buckled rail).
- TCMS: this component shall provide different type of capabilities: dedicated light signals to show train status/GoA level; coaches control; interface for remote control; coupling functionalities; awakening functionalities; advanced doors system; maintenance information transmission to trackside; video recording; doors and platform monitoring; functions activation/inhibition dependent on system status (e.g., inhibition of dynamic brake test).

Cluster	Clause	Exported Constraints
ATP	7.5.4.1.4	All these alternatives will have an impact on SS-026. At this stage, obstacle EOA is the constraint exported to Train Protection and the packet 88 mechanism is proposed for implementation. It is detailed in the following paragraphs.
ATP	TP-1.1	Train Protection shall generate information for automatic handling of track conditions «Powerless section with pantograph to be lowered» and «Powerless section with main power switch to be switched off» according to SS-026 §5.20.2 and §5.20.3.
ATP	TP-2.1	Train Protection shall comply with SS-130 (same interface for GoA2, GoA3 and GoA4).
ATP	TP-3.1	Train Protection shall provide ETCS level to APM.
ATP	TP-4.1	When APM state is AV, Train Protection shall process data entry via interface C5 when a virtual desk is selected by APM or via C25 when a desk is selected by the driver.
ATP	TP-4.2.1	Train Protection shall monitor C16 interface in GoA3 and GoA4. Depending on a configuration parameter, it shall apply service brake or emergency brake in case the connection is lost (APM in FA state is a particular case). A mechanism similar to SS-026 3.16.3.4 (T_NVCONTACT and M_NVCONTACT variables) is proposed.
ATP	TP-4.2.2	Train Protection shall monitor APM state. If APM state changes from GoA3 or GoA4 to AV state while train is running, it shall apply service brake or emergency brake depending on a configuration parameter. Rationale: PER module is lost.
ATP	TP-5.1	Train Protection shall share ETCS referential with APM (LRBG information).

Cluster	Clause	Exported Constraints
ATP	TP-5.2	Train Protection shall be able to interface with the new Localization system.
ATP	TP-6.1	Train Protection shall be interfaced with service brake and emergency brake for GoA3/4 operation. Rationale: no driver.
ATP	TP-7.1	SS-026 3.8.6 function shall be adapted for a co-operative MA received from APM
ATP	TP-8.1	Train Protection shall provide the contextual menu to APM in GoA3 or GoA4. Note: this contextual menu is provided to the driver in GoA1 or GoA2.
ATP	TP-8.2	Train Protection shall receive APM information related to APM actions on the contextual menu when APM state is GoA3 or GoA4 (start button state for example).
ATP	TP-9.1	Train Protection shall generate information for automatic handling of track conditions according to SS-026 §5.20 when APM state is GoA3 or GoA4.
ATP	TP-9.2	Train Protection shall provide Track Condition Change of traction system (packet 39) to TCMS.
ATP	TP-9.3	Train Protection shall provide Track Condition Change of allowed current consumption (packet 40) to TCMS.
ATP	TP-9.4	Train Protection shall provide Track Condition (packet 68) to TCMS.
ATP	TP-9.5	Train Protection shall provide Track Condition Station Platforms (packet 69) to TCMS.
ATP	TP-10.1.1	Train Protection shall request ATP parameters according to train configuration. If the cab is selected by the driver, Train Protection will propose a contextual menu for data entry by the driver through C25 (see SoM Procedure in SS-026 chapter 5). If the cab is selected by APM (virtual cab), Train Protection will propose data entry to REP via C5 without asking for driver ID.
ATP	TP-10.1.2	Train Protection shall request data to REP (ETCS_REP_DATA_ENTRY_REQ packet) after

Cluster	Clause	Exported Constraints
		virtual cab activation by APM and wait for answer (REP_ETCS_TRAIN_DATA packet).
ATP	TP-10.1.3	Train Protection shall compare REP data with Rolling stock data. For gamma trains, the data validation shall be performed by Train Protection. For loco hauled and lambda trains, the validation shall involve Train Protection and TD (not detailed at this stage).
ATP	TP-10.1.4	Train Protection shall send validated ATP parameters (ETCS_REP_VALIDATED_TRAIN_DATA packet with Q_TRAIN_DATA_VALID = 1) after train data have been validated by Train Protection. If the comparison has failed (Q_TRAIN_DATA_VALID = 0), the packet shall deliver to REP the data received by the alternative source.
ATP	TP-10.1.5	Train Protection shall send packet ETCS_REP_VALIDATED_TRAIN_DATA with Q_TRAIN_DATA_VALID = 0 as soon as communication is active and every time the Train Data changes its status in the Train Protection system (after closing of cab for example). For more details, see SS-026 5.4.2.1 and 5.4.3.3 for status affected by SoM and 4.10.1.3 for status affected by mode transition.
ATP	TP-10.1.6	Train Protection shall request operational data to REP (ETCS_REP_TRN_REQ packet) and wait for answer (REP_ETCS_TRN packet). The variables NID_REFERENCE_TRID and NID_OPERATIONAL are determined by application project (both values, NID_REFERENCE_TRID only, NID_OPERATIONAL only or unknown values).
ATP	TP-10.1.7	After data validation, Train Protection shall request APM to start the mission via C16 (ETCS_APM_AVAILABLEFUNC/START_AVAIL) and wait for answer (APM_ETCS_FUNCACTIVATION/ N_START_SELECTION).

Cluster	Clause	Exported Constraints
ATP	TP-10.2	In the current procedure (SS-026 3.18.3.6 and 5.17), it is possible to activate a full service brake and to perform a new data entry at standstill. Without driver, it is proposed to activate a full service brake until the new speed restriction and to run at this speed until next station or rescue point.
ATP	TP-11.1	Train Protection shall monitor the deceleration of the train when emergency brakes are applied.
ATP	TP-11.2	Train Protection shall inform APM when insufficient deceleration is detected at emergency brake application.
ATP	TP-12.1	When Train Protection starts to indicate to the driver that an unprotected LX is being approached, the packet ETCS_APM_TRACKSIDEINFO with variable Q_LX_STATUS set to 0 («Level crossing not protected») shall be sent to APM.
ATP	TP-12.2	When a LX, previously notified to APM as not protected, becomes protected then Train Protection shall send a new ETCS_APM_TRACKSIDEINFO with Q_LX_STATUS set to 1 («Level crossing protected»).
ATP	TP-12.3	When the estimated train front passes a LX, previously notified to APM as not protected, Train Protection shall send ETCS_APM_TRACKSIDEINFO with Q_LX_PASSED set to 1 («Level crossing passed»).
ATP	TP-12.4	Train Protection in OS mode shall monitor the reduced visibility received from APM (revocable TSR with speed 0 km/h transmitted through APM_ETCS_TSR packet).
ATP	TP-12.5	Train Protection shall monitor the remote control speed supervised by TCMS in Remote Control mode.

Cluster	Clause	Exported Constraints
ATP	TP-12.6	Train Protection shall execute a full service brake application request from APM (APM_ETCS_ACTIONS packet).
ATP	TP-12.7	Train Protection shall supervise an obstacle EOA or clear it, depending on APM request (EOA APM_ETCS_ OBSTACLE_EOA packet).
ATP	TP-13.1	Train Protection shall report Train integrity information (SS-026 3.6.5).
ATP	TP-14.1	Train Protection shall provide V_NVONSIGHT value to APM.
ATP	TP-15.1	Train Protection shall execute an emergency brake test when requested by APM.
ATP	TP-15.2	Train Protection shall report result and time of the emergency brake test to APM.
ATP	TP-16.1	The Roll Away Protection (RAP) shall prevent the train from moving in a direction, which conflicts with the current position of the direction controller in the active desk (SS-026 3.14.2.2).
ATP	TP-16.2	The Reverse Movement Protection (RMP) shall prevent the train from moving in the opposite direction to the permitted one. The permitted movement direction of a train shall be the one of the currently valid MA, if available on-board. See chapter 4 concerning permitted direction for special cases (SS-026 3.14.3.1).
ATP	TP-16.3	This function shall prevent the train from moving (SS-026 3.14.4.1).
ATP	TP-17.1	Train Protection shall enter Trip mode when receiving an ES for L1 message from APM.
DM	7.9.1.1.3	The needs of all GoA3/4 modules will correspond to exported constraints to DM, under the form of a specific layer associated to a segment profile of DM for each on-board module. The starting point is the subset-126 with the segment profile information required for ADM.
DM	DM-1.1	DM shall be structured in different layers for providing services to relevant applications

Cluster	Clause	Exported Constraints
		(application engineering shall be required for each layer).
DM	DM-1.2.1	DM layers interfaced to REP shall be dedicated to static data with a version number.
DM	DM-1.2.2	DM layers interfaced to OE shall be dedicated to dynamic data (example: maintenance area).
DM	DM-1.3.1	The start and the end position of any track condition shall be defined by means of a specific vertex lying on the track (see figure 7.11 of chapter 7.4.6).
DM	DM-1.3.2	[Engineering Rule for data preparation]: A vertex shall be defined at the start point and end point of each railway infrastructure element (e.g. tunnel, bridge). These additional vertices complete the vertices used to define rail geometry.
DM	DM-1.3.3	[Engineering Rule for data preparation]: track conditions are always static and predefined. A track condition can be used to improve the perception capabilities in a specific environment where dynamic events could occur (e.g. falling rocks in a canyon area).
ISM	OM-6.1	In GoA3/4, European Instructions shall be transmitted to Train Protection via APM.
ISM	OM-6.2	European Instruction 01 shall be given only when the track is secured (clamping of a point by maintenance staff for example).
ISM	OM-6.3	European Instruction 01 shall not be used for a start of mission. Rationale: Start in FS mode is expected for the nominal case. In case of degraded situation, the acknowledgment of TAF button by the driver should be replaced with a function involving obstacle detection for example.
ISM	ISM-1.1	Trackside detectors shall be managed by the signalling system. They cover only specific locations while an on-board detection permits a continuous check of the environment like done by the driver today (landslide detection for example).

Cluster	Clause	Exported Constraints
ISM	ISM-1.2	Crowd incidents at platform shall be avoided thanks to the crowd management system of TMS.
ISM	ISM-1.3	ISM shall inhibit door closing on request from dispatcher or automatically in stations with a configurable parameter (main station where crowd is expected for example). Door closing authorisation shall be forwarded from APM to TCMS.
ISM	ISM-2.1	ISM shall inform Operation Manager when a train anomaly or driving anomaly impacting operation is reported by REP. Rationale: direct reporting to IM when there is an impact on timetable (more detailed information is only for RU via C48).
ISM	ISM-2.2	ISM shall request APM to force door opening in case of ADM failure in GoA3/4 (opening request failure). Rationale: passengers are blocked in the train and wait for door opening after voice communication with RU.
ISM	ISM-3.1	ISM shall transmit information about incidents to passengers via REP when there is an impact on timetable.
ISM	ISM-4.1	ISM shall transmit European Instructions to REP (see SRS chapter 7.5.11).
LOC	LZ-1.1	LZ shall convert the WGS 84 train position into track coordinates i.e. a confidence interval defined on the path provided by REP.
LOC	LZ-2.1	LZ shall provide current train speed to all on-board logical components.
LOC	LZ-3.1	LZ shall provide the UTC time to all on-board logical components for synchronisation purpose.
MD	MD-1.1	MP and JPs shall always be consistent.
MD	MD-1.2	A TJP task ends always with an End of Journey and is under the responsibility of IM, it cannot be interrupted by RU. Example: a journey between Paris and Brussels should include a dwell time in Lille but if RU tasks are planned in Lille, the

Cluster	Clause	Exported Constraints
		journey must be split into two JPs with a slot dedicated to RU tasks in Lille.
MD	MD-1.3	In GoA3/4 operation, Mission Data (MD) logical component shall check MP consistency in respect to e.g. its structure before sending MP to REP. Refer to Appendix A for the complete structure of MP packet and other packets related to MP.
MD	MD-2.1	If a train is not fully operational, a diagnostic shall be provided at operational level (train maximum speed, maximum braking capacity, possible failure of some doors...) independently of the maintenance details provided through C48.
OE	OE-1.1	All station stopping locations shall be pre-defined as possible rescue points.
OE	OE-1.2	First JP shall include arrival time and departure time for opening the doors at the first station (example: 20 min before departure). Rationale: without arrival time, doors will remain closed in GoA3/4 (or driver will open them in GoA2).
OE	OE-2.1	If a train is not fully operational, a diagnostic shall be provided at operational level (train maximum speed, maximum braking capacity, possible failure of some doors...) independently of the maintenance details. The estimated arrival time is very precise and can be used by TMS to update the JPs.
RAILWAYS ASSET	OM-3.3	The risk of a broken or buckled rail is mitigated by IM. Rationale: it is assumed that track quality is high and well maintained.
RAILWAYS ASSET	OM-3.4	The risk of track-circuit characteristics modified by flooding (mud) is mitigated by signalling. Rationale: line equipped with axle counters, ETCS L3 or landslide detectors.
RAILWAYS ASSET	OM-3.1	Emergency Stop messages shall be sent through Train Control in ETCS level 2.
RAILWAYS ASSET	OM-3.2	Fire in tunnel shall be managed through SS-026 (non-stopping area or tunnel stopping area). Long

Cluster	Clause	Exported Constraints
		tunnels shall be equipped with trackside detectors.
RAILWAYS ASSET	7.5.2.1.13	Assumption: GoA3/4 operation is recommended on lines equipped with a modern interlocking because it relies on ego track for obstacle detection. If there is an area with route ambiguity due to a lack of signalling information, specific measures must be taken like an exported constraint to navigation or an inhibition of GoA3/4 level.
TCMS	TCMS-1.1	TCMS shall cut the traction and open the main circuit breaker before lowering the pantograph.
TCMS	TCMS-1.2	A pantograph problem shall be basically handled by the defined and standardized pantograph detection and protection system (see EN 50206-1, Automatic Dropping Device).
TCMS	TCMS-2	TCMS shall optimize the energy consumption of the vehicle systems: maximize consumption of HVAC during regenerative braking or minimize consumption of HVAC during acceleration, use efficiently the on-board energy storage devices (store energy during regenerative braking or deliver energy to support acceleration).
TCMS	TCMS-3	In GoA4 and on APM request, TCMS shall provide the possibility to open coach windows for fresh air. In GoA3, this need is fulfilled by train attendant.
TCMS	TCMS-6	TCMS shall control a specific lamp on the train to inform that train is either in unattended mode or in remote control mode.
TCMS	TCMS-8.1	TCMS in shutdown mode shall be awakened via C48 and a dedicated message (an alternative solution is a wake-up box connected to the Physical Train Unit and part of Train Adapter). The connectivity of C48 channel shall be tested regularly to check that the connection remains operational even if a train is parked for a week for example.

Cluster	Clause	Exported Constraints
TCMS	TCMS-8.2	Train battery shall provide the energy for train awakening.
TCMS	TCMS-8.3	Train battery healthy status shall be transmitted through C48. Rationale: modern trains raise the pantograph before a battery problem occurs while for other trains, it is assumed that battery is healthy before parking in order to be able to raise the pantograph at wake-up (no charging cable is expected or if yes, it is outside operation).
TCMS	TCMS-8.4	TCMS shall carry out the cab activation within 15 s (new inauguration of the train unit).
TCMS	TCMS-13.1	TCMS shall provide a rough estimation of the number of passengers via weight information and suspension status transmitted to APM. Rationale: weight information should already be used by TCMS for adapting the suspension, current CCTV characteristics are probably not adapted for the counting of passengers. Resolution and coverage should be adapted for this new need if necessary.
TCMS	TCMS-13.2	Maintenance information shall be reported through C48 channel (proprietary messages).
TCMS	TCMS-16	Dedicated sensors shall be available for monitoring weather conditions.
TCMS	TCMS-18.1	TCMS shall release holding brake as soon as traction is applied.
TCMS	TCMS-18.2	The dynamic brake test shall not be initiated by TCMS. Rationale: it could enter in conflict with a traction request from ATO. The feedback of the effective deceleration should be given by the LZ logical component.
TCMS	TCMS-19.1	Traction power shall be applied only when all the doors are closed and locked (TSI LOC&PAS, 4.2.5.5.7).
TCMS	TCMS-19.2	TCMS shall control the Door Management System. TCMS shall combine inputs from Train Protection, ADM, driver (GoA2), APM (replacing the driver in GoA3/4) and speed information for

Cluster	Clause	Exported Constraints
		that purpose. TCMS shall inhibit door opening when train is running.
TCMS	TCMS-19.3	If a key is inserted in the door system by RU staff like today (cleaning, PRM support...), the closing process shall be delayed until the key is released.
TCMS	TCMS-19.4	In the case where the doors are automatically closed for saving HVAC energy, a door can still be opened by passenger until the door closing process starts. After, door opening shall be inhibited.
TCMS	TCMS-19.5	In GoA3/4 and on APM request, TCMS shall isolate a coach by locking its interior doors to forbid passenger access (broken window for example). A similar action is expected on the external doors (EN 15380-4, D.B.K Isolate external doors).
TCMS	TCMS-19.6	Train shall be equipped with an intelligent door system able to manage obstacles and designed to minimize injuries.
TCMS	TCMS-19.8	GoA3/4 exported constraint: Additional sensors shall be provided for monitoring the platform gap along the train. A pure on-board solution is recommended to avoid interoperability issues associated to a trackside implementation like a Platform Screen Door for example. Rationale: The detection of platform gap incidents function is exported to TCMS because the gap between train and platform is rolling stock specific and the function is distributed like for door management. Door system could be improved with cameras to monitor platform gap for example (coverage must include the space between 2 vehicles, if any).
TCMS	TCMS-19.7	TCMS shall try to close the doors a configurable number of times with an increased closing effort when requested by ADM. After the last door closing attempt, TCMS shall force the door closure and reports an anomaly to APM if the door cannot be closed and locked.

Cluster	Clause	Exported Constraints
TCMS	TCMS-25	In GoA4 and on APM request, TCMS shall be able to immobilize the train on a slope (use of spring-loaded brakes for example). In GoA3, this need is fulfilled by train attendant with scotches.
TCMS	TCMS-26	TCMS shall record video material (ring buffer of 1h for example) for further investigation in case of impact. These data shall be transmitted via C48 for incident resolution or via C66 for legal investigation purpose (in case a human is involved).
TCMS	TUM-6.1	Detailed diagnostic information (supplier specific) shall be reported to RU via C48.
TCMS	TUM-10.1	A wake-up command shall power on the train via C48 in order to activate the on-board modules before updating MP. Rationale: On-board modules are not powered when TCMS is in shutdown state (no Status Report). An alternative is to record the awakening time in TCMS via APM before shutdown however it would not cover the case of an earlier departure.
TCMS	TUM-10.2	The connectivity of C48 channel shall be tested regularly to check that the connection remains operational even if a train is parked for a week for example.
TCMS/COUPLING	TCMS-17.11	Coupler heating shall be performed automatically by TCMS when train is awakened if outside temperature is below a given threshold. In case of failure, an anomaly must be reported. For existing trains without TCMS, an adapter function must be provided.
TCMS/COUPLING	TCMS-17.1	The train units shall be equipped with automatic couplers.
TCMS/COUPLING	TCMS-17.2	The coupling process shall be fully automated, no staff shall be involved.
TCMS/COUPLING	TCMS-17.3	TCMS shall offer a coupling mode where TCMS automatically drives the train unit at coupling speed (about 1 km/h, maximum 2 km/h) until it

Cluster	Clause	Exported Constraints
		senses physical contact of the couplers and stops the train.
TCMS/COUPLING	TCMS-17.4	A configurable coupling distance shall define the distance an approaching train shall go at coupling speed before the physical contact. This distance is at minimum as long as the train needs to reliably accelerate to coupling speed, in case its speed is 0 km/h at the beginning of the coupling distance. We expect this distance to be typically about 5m.
TCMS/COUPLING	TCMS-17.5	For capacity reasons, the approaching train shall not travel too long at coupling speed, so not more than about 10m. An approach phase is thus necessary to cover the distance between the maximum safe front end of the approaching train and the minimum safe rear end of the standing train.
TCMS/COUPLING	TCMS-17.6	The approaching train shall not stop before making physical contact however a low coupling speed permits such stop without significant impact on performances.
TCMS/COUPLING	TCMS-17.7	If the standing train is a passenger train, it is required that it can stand with doors open (eventually bridging plates extended, steps open) during the physical joining.
TCMS/COUPLING	TCMS-17.8	Both trains shall be equipped with a TCMS or a TCMS adapter that is able to give the information whether its train unit is ready for joining.
TCMS/COUPLING	TCMS-17.9	A configurable time shall define the joining preparation activities (e.g. opening the coupler cover).
TCMS/COUPLING	TCMS-17.10	TCMS shall close the coupler cover automatically when a configurable critical speed is reached.
TCMS/COUPLING	TCMS-17.12	After physical coupling, TCMS shall start a new train inauguration.

Cluster	Clause	Exported Constraints
TCMS/REMOTE DRIVING	TCMS-12	In remote control mode, TCMS shall act directly on traction or brakes (bypass of Train Protection or ADM commands).
TCMS/REMOTE DRIVING	TUM-7.1	TCMS shall apply the brakes if the communication channel for remote control is lost.
TCMS/REMOTE DRIVING	TUM-7.2	The communication channel for remote control shall be safe. Cybersecurity and delays shall be considered. Remote driving shall require a robust communication system (coverage levels are specified in UIC 951 with a coverage probability of 95 %).
TCMS/REMOTE DRIVING	TUM-7.3	Remote control commands shall be transmitted through C48 and shall comply with the equivalent commands defined in SS-139.
TCMS/REMOTE DRIVING	TUM-7.4	Remote control shall be performed under ETCS supervision. Remote control shall not be possible when ETCS is in SF mode.
TCMS/REMOTE DRIVING	TUM-8.1	Remote control shall be performed through C48 with the support of a camera independent from PER module. Rationale: full coverage of GoA3/4 failure modes.
TCMS/REMOTE DRIVING	DR-9	A camera independent from PER system shall be provided for driving remotely in case of GoA3/4 failure.

Table 3: Exported Constraints expressed in X2Rail-4

5 RELATION WITH INNOVATIVE TECHNICAL ENABLER IN THE CONTEXT OF EUROPE'S RAIL

In the Europe's Rail panorama, APC cluster has detected three Flagship Projects whose field of study has strong relations with Automatic Train Operations. These projects are FP1 MOTIONAL, FP5 TRANSF4M-R and FP6 FUTURE. In the next sections are presented the interactions and the corresponding use cases using as reference the X2Rail-4 architecture.

In the Europe's Rail panorama, APC cluster, within WP4 (D4.1), has detected three Flagship Projects whose field of study has strong relations with Automatic Train Operations. They are FP1 MOTIONAL, FP5 TRANSF4M-R and FP6 FUTURE. The other FPs (FP3 and FP4) instead are treating themes where Automation Processes play a role more oriented on operational level rather than on a technical level; for these reasons no interactions are expected during the evolution of these projects.

5.1 COLLECTION OF INTERACTIONS WITH NEW TE

5.1.1 MOTIONAL

MOTIONAL aims to develop a future European Traffic Management System (TMS) that is interoperable, resilient and able to adapt the capacity, for this reason the technical enablers interacting with Automatic Train Operations are mainly related to the automatic driving function rather than other functionalities belonging to the context of unattended operations. ATO automatic driving from one side processes the optimum speed profile following the instructions coming from TMS - i.e. the timetable contained in the Journey Profile - and to the other provides accurate estimations of arrival times.

In such exchange of information, the following MOTIONAL TEs are involved:

TE1 European cross-border scheduling with international train path planning: ATO system, as highlighted in 2.2, needs trackside data to realize its operations and in order to retrieve the allocated path intended as a list of timing points a univocal key should be agreed. In TSI 2023 this key is identified as NID_OPERATIONAL, but not being univocal at European level can be an obstacle for smooth border transitions.

TE4 Train path and schedule optimisation methods and strategies for capacity efficiency, punctuality and energy saving for different parts of the network and different traffic situations (level of punctuality). TE15 TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables: schedule optimization can take advantage from the arrival times estimated by ATO (TSI 2023) the real challenge is how define the right set of timing point allowing a flexible management of the traffic. It is then important to understand the impacts of new technologies like moving block, of prediction on the clearance of the path.

TE20 Focused on services and solutions that improves the quality of the travel and it is focused on the support to PRM and passengers with special needs: the current ATO up to GoA4 SRS already support management of special needs, for example if PRM requests on board/local staff such activity can be scheduled as dedicated task in the mission profile and the system will act consistently.

5.1.2 TRANSF4M-R

TRANSF4M-R project is aiming to establish rail freight as backbone of the lowest emission and most resilient logistics chain in Europe. It addresses different topics and one of these is regarding the deployment of new technologies such as digital coupling and automation. The relation with APC cluster is predominant in functions like train preparation, shunting operations and automated driving.

The following TRANS4M-R TEs are involved:

TE2 Developing a train composition detection/management system, automated/automatic brake test system, on asset side DAC wagon retrofitting solutions: the automatization of train preparation for loco haul train shall be based on new technologies able to detect train composition. These Train Data able to fulfil the need of ATP and ATO shall be managed by the railway system according to the related safety level. This relation goes further R2DATO and encompass System Pillar.

TE4 Development of systems and solutions for basic autonomous shunting operations. Development of solutions for yard automation including digitalization that enable automated train composition and dispatching (Automated Shunting Operations), including necessary wagon identity system for automated shunting and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions: Taking into account the specific need that this TE could define for autonomous shunting operations the APC system shall check the validity of its principles like mission profile to ensure supporting yard automation.

TE6 Achieving expected consolidation of the expected new freight capabilities, providing requirements and giving feedback to Destination 2 for new automation technology solutions for the automated driving and decision-making as well as automating functions, such as train preparation and basic automatic yard shunting. APC system shall take into account the specific need that this TE is defining.

5.1.3 FUTURE

FutuRe project intends to ensure a new exploitation of regional railway by reducing the total cost of ownership but giving valuable services; this goal could be achieved by using digitalisation, automation new technologies for control command and signalling, wayside components, rolling stock and customer information. For these objectives the deployment of Automatic Train Operations plays a fundamental role because it allows reduction of operational costs and flexibility on shaping the service.

The following FutuRe TE is involved:

TE4 ATO over ETCS adapted to regional operations Hybrid L3, moving block; Traffic Management Systems and C-ITS for regional lines; Cost-effective fail-safe highly accurate train positioning; Cost-effective fail safe on Board Train integrity; Cost-effective fail safe Train Length Detection; Wayside elements for regional railways which are energy self-sufficient and/or wireless enabled; Smart Wayside Object Controller (SWOC); New propulsion train refuelling /recharging station; Virtualisation in Rolling Stock design. APC cluster shall collaborate in order to ensure the effectiveness of ATO in specific trackside contexts, such as moving block or equipped with non-protected level crossing and the capability to support dedicated services like stop on request.

5.2 RELEVANT UC IDENTIFICATION SHOWING EXPLOITATION OF INNOVATIVE TECHNICAL ENABLER

5.2.1 MOTIONAL

TE1 European cross-border scheduling with international train path planning: in Table 4 and Table 5 the relevant use cases developed in R2DATO WP5 or previous projects are listed.

ID	Use Case Name	Summary
UC5.1-031	Border crossing	General passing of a geographical border.
UC5.1-002	Prepare passenger train (diesel)	This scenario outlines the process of getting a passenger train ready for operation, particularly one powered by diesel. The main goal of this train preparation is to guarantee the safety of the rail vehicles and ensure they are set up correctly to enter the rail network.
UC5.1-003	Prepare train unit for a mission - Configure GoA automatically	After Powering on the train, TAS provides OAS with all profiles needed for the mission. There are three sources for GoA level: 1. Static track plan data (static Segment Profile). 2. Dynamic information from dynamic Segment Profile from IM (OE). 3. Dynamic information from Mission Profile from RU
UC5.1-004	Prepare train unit for a mission – Select traction system automatically	The use case, Prepare Train unit for a Mission, normally happens after the X2R4 use case “"Awakening sequence of autonomous train" and the originally identified use case “Switch traction power supply to a train unit while stationary” is part of this use case. The selection or the switch of traction power supply is expected to be automatic to: Select voltage level. Select voltage type in the catenary. React on powerless section.
UC5.1-008	Conduct visual inspects & tests	As part of the protocol to prepare the train for departure, the driver needs to perform visual inspections and tests. This use case only considers the visuals examinations. It is assumed that the visual inspection will be performed periodically before the train is cleared for automatic operation or RO operations by authorised personnel.

UC5.1-009	Conduct system and functional tests	As part of the protocol to prepare the train for departure, the driver needs to perform visual inspections and system functional tests. This Use Case only considers the system functional checks.

Table 4: R2DATO WP5 use cases relevant for MOTIONAL TE1

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-031 Border crossing	R22 TM handover R23 TMS handover	13.2.2 Entry in technical centre 13.2.3 Exit from technical centre
UC5.1-002 Prepare passenger train (diesel)	R3 Prepare train for mission	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration 13.5.1 Prepare freight train
UC5.1-003 Prepare train unit for a mission – configure GoA automatically	R3 Prepare train for mission R21 GoA transitions	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration 13.5.1 Prepare freight train
UC5.1-004 Prepare train unit for a mission – Select traction system automatically	R3 Prepare train for mission	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration

		13.5.1 Prepare freight train
UC5.1-008 Conduct visual inspects & tests	R3 Prepare train for mission	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration 13.4.3 Test brakes dynamically 13.4.4 Activate horn 13.5.1 Prepare freight train
UC5.1-009 Conduct system and functional tests	R3 Prepare train for mission R4 Prepare train for departure	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.3 Initialisation sequence for a multiple unit movement 13.3.4 Train Protection configuration 13.4.2 Check departure conditions except signalling 13.4.3 Test brakes dynamically 13.4.4 Activate horn 13.4.6 Authorize departure of autonomous train 13.5.1 Prepare freight train 13.5.2 Supervise departure of autonomous freight train

Table 5: Previous projects use cases relevant for MOTIONAL TE1

TE4 Train path and schedule optimisation methods and strategies for capacity efficiency, punctuality and energy saving for different parts of the network and different traffic situations (level of punctuality). TE15 TMS speed regulation of trains, precise routes and target times for ATO and

dynamic timetables: in Table 6 and Table 7 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-014	Perform mission	This use case describes the process of carrying out a mission that has been previously defined. This is a general umbrella use case that describes the assignment of mission segments (journeys to perform mission movement as well as stopping segments; tasks to be conducted if train is stopped). The mission is considered complete when all the segments have been completed. If necessary (due to disruptions, emergencies etc.), a mission can be modified (if conditions for modifying the current mission are met) or aborted before all segments have been completed.
UC5.1-015	Skip station by passenger service	The train is scheduled to skip a station without a stop, considering a limited speed for passing through the station.
UC5.1-016	Implementing discretional stops by regional services	This use case describes the need of passengers on-board or travellers on platform to request stops at some stations. Those stations are usually in less frequency request to stop. When no request on stops, Serviceable train will skip those stops and continue the journey. In GoA1, this need is taken in charge by Driver. Starting from GoA2, this need can be taken in charge automatically by systems.
UC5.1-019	Stop at platform for passenger service	The train approaches the scheduled passenger exchange position, where it stops precisely. Passenger doors are prepared for opening and passengers are informed in order to achieve an efficient passenger exchange.
UC5.1-031	Border crossing	General passing of a geographical border;
UC5.1-035	Perform automatic train shunting and "special" movements: Non-scheduled stop, stop at next emergency stop area.	This use case aims to illustrate the actions to be taken in case a train needs to perform a non-scheduled stop as a result of a degraded situation or emergency. For example, it could be needed to stop at a station after a passenger triggers an alarm handle.

Other UC		All other use cases managing an unexpected situation, shall bring to a similar solution at TE1, TE15 side, rational these TEs are focused on traffic regulations and not on management of specific incident.

Table 6: R2DATO WP5 use cases relevant for MOTIONAL TE4 and TE15

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-014 Perform mission	R5 Drive according to journey R7 React to mission update	13.3.6 Deactivate vigilance 13.4.1 Move autonomous train 13.4.3 Test brakes dynamically 13.4.8 Traction and brake control 13.4.9 Request holding brake 13.6.1 Manage passenger information systems 13.7.7 Update mission
UC5.1-015 Skip station by passenger service	NR3 Driver initiated “Stopping point Skip”	*X2R4 GoA2 scenario
UC5.1-016 Implementing discretional stops by regional services	R6 React to journey update	13.4.7 Determine stopping point for a freight or passenger train 13.6.1 Manage passenger information systems 13.8.1 React after misrouting
UC5.1-019 Stop at platform for passenger service	R10 Train stops at stopping point	13.4.7 Determine stopping point for a freight or passenger train 13.4.9 Request holding brake 13.11.3 Passenger train only stops partially at a platform
UC5.1-031 Border crossing	R22 TM handover R23 TMS handover	13.2.2 Entry in technical centre 13.2.3 Exit from technical centre
UC5.1-035 Perform automatic train shunting and "special" movements: Non-scheduled	R36 Train stops by signalling NR4 Hold train at next Stopping Point	13.7.2 Unexpected stop 13.7.5 Request immobilisation 13.7.12 Stop at next station or rescue point

stop, stop at next emergency stop area.		
Other UC		All other use cases managing an unexpected situation, shall bring to a similar solution at TE1, TE15 side, rational these TEs are focused on traffic regulations and not on management of specific incident.

Table 7: Previous projects use cases relevant for MOTIONAL TE4 and TE15

TE20 Focused on services and solutions that improves the quality of the travel and it is focused on the support to PRM and passengers with special needs: in Table 8 and Table 9 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-014	Perform mission	This use case describes the process of carrying out a mission that has been previously defined. This is a general umbrella use case that describes the assignment of mission segments (journeys to perform mission movement as well as stopping segments; tasks to be conducted if train is stopped). The mission is considered complete when all the segments have been completed. If necessary (due to disruptions, emergencies etc.), a mission can be modified (if conditions for modifying the current mission are met) or aborted before all segments have been completed.
UC5.1-019	Stop at platform for passenger service	The train approaches the scheduled passenger exchange position, where it stops precisely. Passenger doors are prepared for opening and passengers are informed in order to achieve an efficient passenger exchange.

Table 8: R2DATO WP5 use cases relevant for MOTIONAL TE20

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-014 Perform mission	R5 Drive according to journey R7 React to mission update	13.3.6 Deactivate vigilance 13.4.1 Move autonomous train 13.4.3 Test brakes dynamically

		13.4.8 Traction and brake control 13.4.9 Request holding brake 13.6.1 Manage passenger information systems 13.7.7 Update mission
UC5.1-019 Stop at platform for passenger service	R10 Train stops at stopping point	13.4.7 Determine stopping point for a freight or passenger train 13.4.9 Request holding brake 13.11.3 Passenger train only stops partially at a platform

Table 9: Previous projects use cases relevant for MOTIONAL TE20

5.2.2 TRANS4M-R

TE2 Developing a train composition detection/management system, automated/automatic brake test system, on asset side DAC wagon retrofitting solutions: in Table 10 and Table 11 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-002	Prepare passenger train (diesel)	This scenario outlines the process of getting a passenger train ready for operation, particularly one powered by diesel. The main goal of this train preparation is to guarantee the safety of the rail vehicles and ensure they are set up correctly to enter the rail network.
UC5.1-008	Conduct visual inspects & tests	As part of the protocol to prepare the train for departure, the driver needs to perform visual inspections and tests. This use case only considers the visuals examinations. It is assumed that the visual inspection will be performed periodically before the train is cleared for automatic operation or RO operations by authorised personnel.
UC5.1-009	Conduct system and functional tests	As part of the protocol to prepare the train for departure, the driver needs to perform visual inspections and system functional tests. This Use Case only considers the system functional checks.

Table 10: R2DATO WP5 use cases relevant for TRANSF4M-R TE2

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases

UC5.1-002 Prepare passenger train (diesel)	R3 Prepare train for mission	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration 13.5.1 Prepare freight train
UC5.1-008 Conduct visual inspects & tests	R3 Prepare train for mission	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.4 Train Protection configuration 13.4.3 Test brakes dynamically 13.4.4 Activate horn 13.5.1 Prepare freight train
UC5.1-009 Conduct system and functional tests	R3 Prepare train for mission R4 Prepare train for departure	13.2.1 Elaborate mission and journey profiles 13.2.7 Validate human interaction 13.3.2 Operations to test safety contributors 13.3.3 Initialisation sequence for a multiple unit movement 13.3.4 Train Protection configuration 13.4.2 Check departure conditions except signalling 13.4.3 Test brakes dynamically 13.4.4 Activate horn 13.4.6 Authorize departure of autonomous train 13.5.1 Prepare freight train

		13.5.2 Supervise departure of autonomous freight train

Table 11: Previous projects use cases relevant for TRANSF4M-R TE2

TE4 Development of systems and solutions for basic autonomous shunting operations. Development of solutions for yard automation including digitalization that enable automated train composition and dispatching (Automated Shunting Operations), including necessary wagon identity system for automated shunting and cover important preparatory works with higher TRL for the future set of demonstration foreseen in the Multi- annual Work programme in view of the evolutions of the solutions: in Table 12 and Table 13 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-027	Operate Full autonomous trains at low speed <= 30km/h in stabling yard or shunting Area equipped or not with ETCS infrastructure	Full autonomous operations of trains at low speed < 30 km/h in stabling yard or shunting area equipped or not with ETCS infrastructure based on X2R SRS. The vehicle moves from current position to demanded position and stops there.
UC5.1-029	Perform transition from CBG to NCBG	This use case describes the CBG-to-NCBG transition (centrally vs non centrally controlled), and only covers transition between CBG-NCBG (drive up to S-board and receive permission to enter NCBG).
UC5.1-030	Perform transition from NCBG to CBG	Transition from RD control inside an NCBG (non-centrally controlled area) to either ATO control or continued RD control in a CBG (centrally controlled area).

Table 12: R2DATO WP5 use cases relevant for TRANSF4M-R TE4

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-027 Operate Full autonomous trains at low speed <= 30km/h in stabling yard or shunting Area equipped or not with ETCS infrastructure	R30 Drive inside depot, stabling or maintenance facility	13.2.2 Entry in technical centre 13.2.3 Exit from technical centre
UC5.1-029	R28 Transition from ATP Class B area to Class A area	13.2.2 Entry in technical centre

Perform transition from CBG to NCBG		
UC5.1-030 Perform transition from NCBG to CBG	R29 Transition from ATP class A area to Class B area	13.2.3 Exit from technical centre

Table 13: Previous projects use cases relevant for TRANSF4M-R TE4

TE6 Achieving expected consolidation of the expected new freight capabilities, providing requirements and giving feedback to Destination 2 for new automation technology solutions for the automated driving and decision-making as well as automating functions, such as train preparation and basic automatic yard shunting: in Table 14 and Table 15 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-014	Perform mission	This use case describes the process of carrying out a mission that has been previously defined. This is a general umbrella use case that describes the assignment of mission segments (journeys to perform mission movement as well as stopping segments tasks to be conducted if train is stopped). The mission is considered complete when all the segments have been completed. If necessary (due to disruptions, emergencies etc.), a mission can be modified (if conditions for modifying the current mission are met) or aborted before all segments have been completed.

Table 14: R2DATO WP5 use cases relevant for TRANSF4M-R TE6

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-014 Perform mission	R5 Drive according to journey R7 React to mission update	13.3.6 Deactivate vigilance 13.4.1 Move autonomous train 13.4.3 Test brakes dynamically 13.4.8 Traction and brake control 13.4.9 Request holding brake 13.6.1 Manage passenger information systems 13.7.7 Update mission

Table 15: Previous projects use cases relevant for TRANSF4M-R TE6

5.2.3 FUTURE

TE4 ATO over ETCS adapted to regional operations Hybrid L3, moving block; Traffic Management Systems and C-ITS for regional lines; Cost-effective fail-safe highly accurate train positioning; Cost-effective fail safe on Board Train integrity; Cost-effective fail safe Train Length Detection; Wayside elements for regional railways which are energy self-sufficient and/or wireless enabled; Smart Wayside Object Controller (SWOC); New propulsion train refuelling /recharging station; Virtualisation in Rolling Stock design: in Table 16 and Table 17 are listed the relevant use cases developed in R2DATO WP5 or previous projects.

ID	Use Case Name	Summary
UC5.1-014	Perform mission	This use case describes the process of carrying out a mission that has been previously defined. This is a general umbrella use case that describes the assignment of mission segments (journeys to perform mission movement as well as stopping segments; tasks to be conducted if train is stopped). The mission is considered complete when all the segments have been completed. If necessary (due to disruptions, emergencies etc.), a mission can be modified (if conditions for modifying the current mission are met) or aborted before all segments have been completed.
UC5.1-015	Skip station by passenger service	The train is scheduled to skip a station without a stop, considering a limited speed for passing through the station.
UC5.1-016	Implementing discretional stops by regional services	This use case describes the need of passengers on-board or travellers on platform to request stops at some stations. Those stations are usually in less frequency request to stop. When no request on stops, Serviceable train will skip those stops and continue the journey.
UC5.1-019	Stop at platform for passenger service	The train approaches the scheduled passenger exchange position, where it stops precisely. Passenger doors are prepared for opening and passengers are informed in order to achieve an efficient passenger exchange.
UC5.1-045	Handle failure of tilting technology infrastructure - Malfunction of tilting technology Infrastructure	This use case describes the procedure to restrict tilting trains due to failures of the infrastructure equipment (failure in data transmission from data point like balises or missing data point). The aim of the restriction is to avoid following tilting brakes to stop (forced brake) due to failures or missing data points and operate without interruption.

Table 16: R2DATO WP5 use cases relevant for FutuRe TE4

Task 5.1 Use Cases	X2R4 Operational Scenarios	X2R4 SRS Use Cases
UC5.1-014 Perform mission	R5 Drive according to journey R7 React to mission update	13.3.6 Deactivate vigilance 13.4.1 Move autonomous train 13.4.3 Test brakes dynamically 13.4.8 Traction and brake control 13.4.9 Request holding brake 13.6.1 Manage passenger information systems 13.7.7 Update mission
UC5.1-015 Skip station by passenger service	NR3 Driver initiated “Stopping point Skip”	*X2R4 GoA2 scenario
UC5.1-016 Implementing discretional stops by regional services	R6 React to journey update	13.4.7 Determine stopping point for a freight or passenger train 13.6.1 Manage passenger information systems 13.8.1 React after misrouting
UC5.1-019 Stop at platform for passenger service	R10 Train stops at stopping point	13.4.7 Determine stopping point for a freight or passenger train 13.4.9 Request holding brake 13.11.3 Passenger train only stops partially at a platform
UC5.1-045 Handle failure of tilting technology infrastructure - Malfunction of tilting technology Infrastructure	NR12 Equipment fault infrastructure	13.10.1 Sudden lack of catenary voltage 13.10.4 Point failure with movement permission 13.10.5 Point failure without movement permission 13.10.6 Damage to catenary 13.10.7 Damage to Level Crossing 13.10.8 Damage to Level Crossing

Table 17: Previous projects use cases relevant for FutuRe TE4

6 CONCLUSIONS

We are currently witnessing multiple initiatives in the railway sector aimed at finding a solution for automating train operations. However, due to the various inputs available, it is difficult to compare the outcomes. This can be attributed to the fact that these outcomes are specific to certain applications and the conditions and assumptions used in each study to simplify the complex problem are always different. Starting from these evidence, Task 5.3 has taken on the responsibility, given by Europe's Rail, of making the experience of Shift2Rail more applicable to the topic of Automatic Train Operations. The aim is to identify which elements are already well-designed and which areas need improvement.

In this scenario, Task 5.3 has taken from Europe’s Rail the mandate to make the experience of Shift2Rail more usable for the topic of Automatic Train Operations, highlighting which elements are already in a good design shape and which are the points that need to be strengthened.

The team, by leveraging their wide skills in the railway sector, has then worked on the input documents delivered by different projects to consolidate the outcomes achieved even if belonging to different projects (like X2Rail-4, TAURO and ARCC).

WP6 of R2DATO is the work package entitled to hand over the design activities of X2Rail-4 and its tasks take advantage of the analysis provided by this deliverable to facilitate the comprehension of SRS up to GoA4 principles. It provides information on the points that are not yet consolidated and the functions that require further definition. The outcomes of D3.5 also play a role in a broader context by describing the exported constraints that ATO up to GoA4 solution expects from other railway components such as TCMS, ATP and trackside. Furthermore, the relationships with other Flagship Projects were analysed through a list of use cases that involve the interaction of different technologies.

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