Rail to Digital automated up to autonomous train operation

D19.1 – Train Integrity and Train Length Architecture & Functional Requirements

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EXECUTIVE SUMMARY

The activities related to Train Integrity and Train length described in this document are linked to the task 19.1 of WP19 of R2DATO project and are in line with the R2DATO Grant Agreement. The activities and meetings carried out during the task 19.1 (included subtasks 19.1.1 and 19.1.2) have been reported in the document and represent the macro areas into which the current document is divided.

To have solutions based on ERTMS/ETCS Moving Block or Hybrid Level 3, it becomes essential that the integrity of the train and the length of the train can be assessed on board the train. These innovations are a consequence of the desire to minimize the distance between trains managed by the signalling systems. Furthermore, to manage the length of the train we want to reduce the driver's intervention to a minimum; therefore, a system must be able to autonomously detect this length.

The TSI - Mandatory specifications (ETCS B4 R1, RMR: GSM-R B1 MR1 + FRMCS B0, ATO B1 R1) report these functions and therefore it becomes essential to create solutions that are in line with the specifications.

What was shared during the activities of task 19.1 related to what the added value was introduced and how the process of harmonizing the different technologies that emerged from previous projects could be simplified.

The objective of Task 19.1 is to consolidate the specifications of train integrity and train length as a starting point for WP20 in which the development of the demonstrators is envisaged.

The first part of the project was dedicated to the critical analysis of the documentation produced and the comparison with the operational needs expressed. Previous X2Rail-2 and X2Rail-4 designs produced multiple architectures for train integrity and length. The set of requirements and architectures allowed all partners to align themselves quite quickly with the state of the art.

For this reason, the results obtained in previous projects, in particular X2Rail-2 and X2Rail-4, were analysed. This document only reports the evolutions compared to what was done previously.

The functional aspects for Train Integrity (OTI-I) and those for determining the Train Length (OTI-L) are kept separate because they have different functions, but this does not exclude that the same system can implement both functions.

One of the aspects highlighted by the evaluations carried out is that in the state of the art presented by previous projects it was not possible to join two trains that had different technologies for determining the length and integrity of the train. Another aspect, also reported in the GA, concerns the use of the DAC also to obtain these functions.

The objectives that guided the activities of WP19 for the consolidation of the specifications were therefore mainly: i) Reinforcement of existing requirements when necessary; ii) Introduction of the DAC; iii) Streamlined management for the combined use of different technologies.

In collaboration with the System Pillar and the FP5, a first document was drawn up which summarizes the salient aspects of the functioning of the DAC towards obtaining the OTI-I and OTI-L functions. This was the starting point of our activities to start considering the DAC as one of the possible elements for satisfying our objectives.

In order to ensure that entities that provide their own integrity and length using different technologies can interact and combine, the concept of “OTI Unit” (OTI-U) and “OTI Composition” (OTI-C) was introduced. This represents a novelty compared to the previous narrative.

This concept provides that an OTI-C is considered to all intents and purposes an entity which can evaluate its own integrity and determining its own length. When this entity couples with another similar entity then one of these takes the role of Master and the other of Slave. The OTI-U can be realized and represented by a physical single device, or a function implemented by another computer, e.g. TCMS or EVC.

The process is transparent in the sense that within the entity the train integrity and train length are processed according to the type of technology applied and only the macro information relating to length and integrity is provided outside the OTI-C entity.

In this way two OTI Compositions can interact even if the technology used for the OTI-I and OTI-L functions for every OTI-U/OTI-C is different.

In the activities of WP19 the interface between two OTI-Cs was defined only at the functional level (FFIS) but the next step will be to define an FFFIS interface.

The results reported here can be summarized in: i) alignment with TSI Baseline 4 and consolidation of specifications; ii) clarification of the operational aspects related to Train Integrity and Train Length; iii) inclusion of the use of the DAC at a functional level; iv) introduction of the concept of OTI Unit and OTI Composition.

ABBREVIATIONS AND ACRONYMS

Abbreviation Acronym	Description
ATO	Automatic Train Operation
CONFIRMED	Train Integrity is confirmed by the OTI-I
CONFIRMED DR	Train Integrity is confirmed by the Driver
DAC	Digital Automatic Coupling
DMI	Driver Machine Interface
EoM	End of Mission
ERJU	Europe’s Rail Joint Undertaking
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EVC	European Vital Computer
FFFIS	Form-Fit Functional Interface Specification
FP5	Flag Ship Project of Europe’s Rail Joint Undertaking
FSM	Finite State Machine
GA	Grant Agreement
HL3	Hybrid Level 3
LOSS	Train Integrity Lost in FSM
LOST	Train Integrity is Lost
NR	Not Regular Mode in FSM
OBU	On-Board Unit
ORS	Operational Requirement Specification
OTI-C	On-Board OTI Composition Function
OTI-I	On-Board Train Integrity Function
OTI-L	On-Board Train Length Function
OTI-U	On Board OTI Unit Function
PO	Power On
R	Regular Mode in FSM
R2DATO	Rail to Digital automated up to Autonomous Train Operation
SI	Système International (International System of Units)
SoM	Start of Mission
TCDF	Train Composition Determination Function
TCMS	Train Control & Management System
TIMF	Train Integrity Monitoring Function
TLD	Train Length Determination
TLDF	Train Length Determination Function
TMS	Traffic Management System
TSI	Technical Specifications for Interoperability
UC	Use Case
UNKNOWN	Train Integrity isn’t valuable, Is in Unknown state

USn	User Story “n”
WMC	Wayside Maintenance Centre
WPn	Work Package number “n” of R2DATO project
X2Rail-n	X to Rail project “n” of IP2 Shift2Rail

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

1 INTRODUCTION

This document inside the framework of R2DATO project, provides the Consolidation of Train Integrity & Trail Length Determination Specification.

In line with the GA The activities of task 19.1 and subtask 19.1.1 and subtask 19.1.2, are focused on consolidating the activities carried out in the X2Rail2 and X2Rail4 projects of IP2 Shift2Rail.

The purpose of this document is to make a summary of the possible applicable solutions and also to introduce the use of the DAC when ready to host the functions necessary for determining the integrity and the length of the train.

The objective of the activities in WP19 is to obtain a system that is independent of the applied technologies and allows it to be used with two trains not equipped by the same supplier.

One of the objectives of this work is to consolidate the interfacing with the ETCS On-Board system, which is the main user, together with the driver, of the processed information.

This Deliverable D19.1 is linked to R2DATO WPs in detail to WP15, WP16, WP13 and WP14 where the train Integrity and the Train length are expected for the Hybrid Level 3 and Moving Block application.

The document reports mainly the upgrade respect the activities performed in the previous project, in particular in X2Rail-2 and X2Rail-4.

One important issue is, when is possible, to manage the train as a virtual element that provide its train integrity and train length information.

This approach is also applicable when the DAC is present and allow to design a common solution applicable in all the linked configurations.

To maintain consistency with what was achieved in previous projects in X2Rail-2 and X2Rail-4, the OTI-I and OTI-L notations are retained to identify the Train Integrity Monitoring and Train Length Determination functions respectively. In TSI the TIMF notation is used equivalently which refers to OTI-I.

1.1 SCOPE

This document constitutes the Deliverable D19.1 “Train Integrity and Train Length Architecture & Functional Requirements” in the framework of the WP 19 of FP2 R2DATO.

The document offers a collection of Operational requirements Use Case Architecure and Functional Requirements divided into categories as indicated in the Table 1.

1.2 PURPOSE

The purpose of this document is to provide a solid basis of description of the Train Integrity and Train Length Function in term of Operational Requirements Use Case Architecture and Functional Requirements.

These are only the upgrade part respect the input documents described in Development Methodology.

§	Title	Description
2	**Development Methodology**	Describe the activities performed for obtain this document
3	**Operational Requirement Specification**	Reports the Operational Requirement that are mainly coming from the final users of OTI-I and OTI-L
4	**User Stories and Use Cases**	In this chapter coming from the input of chapter 3 are reported the new Use Story and Use Cases linked to the introduction of DAC
5	**Train Integrity and Train Length Architecture**	In this chapter the concept of OTI Composition is developed together with the high-level definition of the different possible architectures.
6	**OTI Interfaces**	Describe the interfaces of the OTI
7	**Train Integrity and Train Length Requirements**	In this chapter only new requirements (respect to previous projects) are reported
	Conclusions	The results obtained and the conclusions are contained in this chapter.
	Appendix 1	Reports all the requirement produced in the document
	Appendix 2	Reports a Special Case for Train Length determination

Table 1: Document Structure

1.3 Limitations

The document version presents the interface for OTI Composition (OTI-C) in FFIS version. This does not prevent the development of solutions but may compromise their interoperability.

2 DEVELOPMENT METHODOLOGY

In this section, the methodology on how this deliverable was developed is discussed. The methodology section is split out in three sections: i) Deliverable Objectives; ii) Process Overview; iii) Existing and Relevant Documents; iv) Methodology for Deliverable Development.

2.1 DELIVERABLE OBJECTIVES

This deliverable is created on the basis of the guidelines as described in the Grant Agreement. From GA the WP19 has this mandate:

In the ETCS Level3, where train detection systems are not mandatory, it is necessary to check the integrity of the train using an on-board system. Moreover, for simplification of the driver activities at the start of mission it is important to adopt an independent system able to calculate the length of the train. In order to realise this, the Train Integrity and Train Length Determination work package uses the results obtained in the previous X2Rail 2 and X2Rail 4 projects in addition to those of the future DAC (FA5) project. The solution must also respect the results of the Moving Block (ETCS Level 3) definitions which are dealt with within TE10. It will have to satisfy the requirements derived from the ETCS Level 3 development for main line but also evaluate the feasibility of requirements coming from FA5 and FA6. Especially the collaboration with the DAC project will serve to consolidate a solution that can be used in any operational context. Furthermore, the architectural solution must conform to the inputs coming from the System Pillar. A first version of the specific requirements coming from FA5 and FA6 is expected in M6 which will be given feedback in M8. The feasible and therefore accepted requirements from FA5 & FA6 will be part of deliverable D19.1. An interaction with WP13 and WP15 is established to consolidate functional interfaces with EVC. The expected goal of this work package is the consolidation of requirements for the Train Integrity and Train Length Determination solutions and their insertion into the on-board architecture.

***Task 19.1**: Architecture & Functional Requirements (Leader: MERMEC; Participants: ADIF, DB, INDRA, MERMEC, ÖBB-PV, SMO, FT, FSI, HITACHI) (Duration: M01 to M12) In this task a continuous interaction with the System Pillar, FA5 and FA6 is needed to define the requirements for the architecture of the Train Integrity and Train Length Determination. A proactive interaction is carried out aimed at defining the two functions inside the CCS On Board architectures. As a common between the two functions, it collects all the requirements that are in common between them. The requirements that will apply to Train Integrity or Train Length Determination only will be highlighted.*

***Sub-task 19.1.1**: Operational requirement specification (ORS) (Leader: OBB-PV; Participants: ADIF, DB, INDRA, MERMEC, SMO, FT, HITACHI) An ORS applicable for the Train Length and Train Integrity Determination for all kind of railways operation will be established within this task. Various sources such as other work packages and the System Pillar will be respected. If new requirements are identified, they will be shared within FP2-R2DATO and with the other FAs.*

***Sub-task 19.1.2:** Train Integrity and Train Length Requirements (Leader: FT; Participants: DB, INDRA, MERMEC, ÖBB-PV, SMO, FT, HITACHI, ADIF) All functional and non-functional requirements relating to the Train Integrity and Train Length Determination are identified and consolidated within this task. If there are specific requirements for Main Lines, Freight lines and Regional lines they will be highlighted.*

On basis of the description that was provided in the GA, the following can be concluded that are propaedeutic for the creation of the D19.1:

1. Relevant input from partner projects (X2Rail2, X2Rail4, other FAs and SP) needs to be collected, analysed and if relevant, included in the deliverable. Input from these partners project will be considered until month 6, June 2023, of the project.
2. Task 19.1 in this task there are two main activities, one is to be in touch with System Pillar and other FAs and second coordinate the activities of the Sub-Task for the implementation of the deliverable.
3. Sub-Task 19.1.1 Starting from what is already present in previous project this sub task collects the Operational Requirement Specification coming mainly from relevant areas like Railways Undertaking and Infrastructure Managers. If any input coming from SP are taken into account.
4. Sub-Task 19.1.2 Starting from the input coming from the previous project the additional Functional and non-functional requirements are elaborated.

2.2 Process Overview

The Figure 1 shows the process followed in task 19.1 to obtain Deliverable D19.1.

As can be seen from the process shown in the Figure 1, the main steps that participated in the achievement of the final document are indicated.

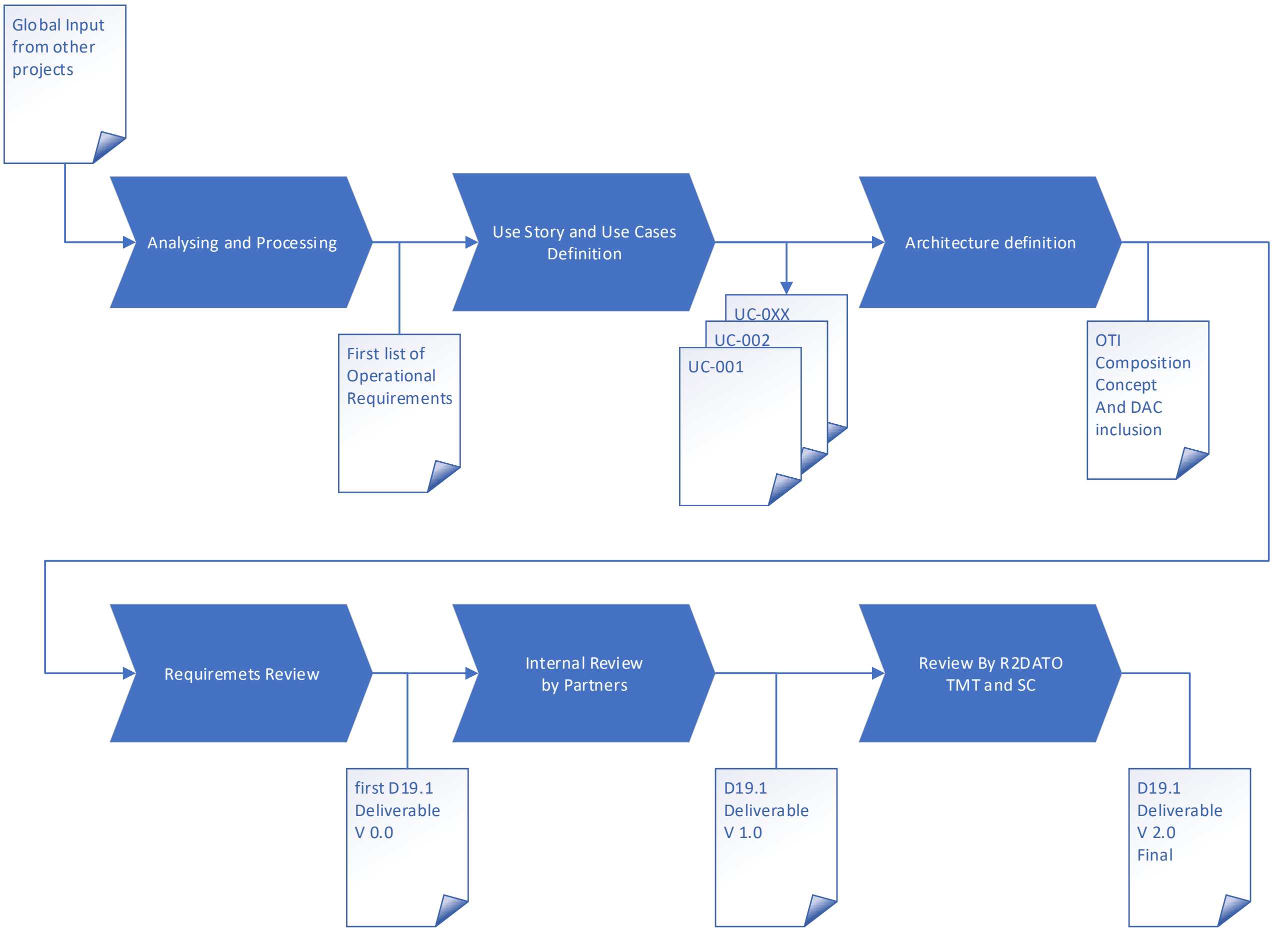

Figure 1: Process Overview

2.3 EXISTING AND RELEVANT DOCUMENTS

As input to the Work Package 19 process, the state of the art was considered and deliverables from past projects were identified and actively requested at the Work Package level. For this process, inputs were collected from several relevant projects:

- X2Rail-2 - Deliverable D4.1 Train Integrity Concept and Functional Requirements Specifications v. 2.3
- X2Rail-2 - Deliverable D4.2 Functional architecture & Interfaces specifications & Candidate technologies selection v. 3.0
- X2Rail-2 - Deliverable D4.3 Test scenarios & test cases specifications v. 2.0
- X2Rail-4 - D7.3 Standardisation Proposal v. 1.2
- X2Rail-4 - Deliverable D7.2 OTI Technology Migration v. 2.0
- System Pillar Task 4 DAC / FDFTO WP3.1 FDFTO-ERTMS/ETCS v. 1.0 date 2023/10/31
- ERTMS/ETCS Train Interface FFFIS - SUBSET-119 ISSUE: 4.0.0 DATE: 2023-07-05

To avoid further delay and ensure a viable result before the deadline M12 of WP19, the work package team started work on the basis of these deliverable and draft documents, establishing the potential gap with the intended WP19 results.

2.4 METHODOLOGY FOR DELIVERABLE DEVELOPMENT

The deliverable 19.1 is one of the early deliverables inside the Cluster Optimized Headway of R2DATO. This work group relied on deliverables from the Shift2Rail programs of X2Rail-2 and X2Rail-4. In parallel, inputs were also sourced through the SP. These became the fundamental inputs to start the process of input collection.

The work carried out in Task 19.1 and in sub-tasks 19.1.1 and 19.1.2 involved the study and further study of the results obtained in previous projects.

Without prejudice to the valid work carried out in X2Rail-2 and X2Rail-4, a series of points have been highlighted by the WP19 partners which are reported below:

- Trains equipped with solutions made with different technology do not necessarily interface easily;
- It is necessary to integrate the DAC among the possible applicable solutions;
- A standard interface to the ETCS on-board system must be defined;
- For cost effective solutions more integrated solutions are possible;
- There may be impacts to the DMI ETCS interface.

Once these activity development points have been identified, the first step was to define the operational aspects in which Train Integrity and Train Length shall operate.

To avoid rewriting the parts that are considered valid present in the X2Rail-2 and X2Rail-4 deliverables, only what is considered to be an improvement or a modification is reported in deliverable D19.1.

It will then be the task of WP20 in the specifications consolidation phase to report an exhaustive and complete list of the reference specifications for the demonstrator's development.

To resolve the points that were highlighted during the analysis of the documents, the areas of intervention that correspond to the subsequent chapters of this document.

Once the chapters were drafted, the workgroup followed a structured approach from the point of drafting the chapters to finalizing of the deliverable with the required consensus and approval. The following steps illustrate this process:

1. First development stage – responsibility of partner writing the chapters;
2. Review – responsibility of partner reviewing the chapters;
3. Second development stage – responsibility of partner writing the chapters;
4. Formal review – responsibility of partner reviewing the document;
5. Third development stage – responsibility of partner writing the document;
6. Finalized (stored in Cooperation Tool the Deliverable document D19.1) – responsibility of partner writing the document;

As can be seen in the process described, it provided with a good collaboration among the partners for writing and reviewing the chapters before agreeing on the finalized document.

3 OPERATIONAL REQUIREMENT SPECIFICATIONS

3.1 General Operational Requirements

The general scenario, in which both the determination of the integrity of the train and the calculation of the length of the train operate, involves the actors:

- OTI-I and OTI-L functions
- ETCS OBU
- Train Driver
- TMS

The type of involvement will be specified each time.

Op Req1. Both train integrity (OTI-I) and train length (OTI-L) functions shall be automatically reset / re-evaluated when the cab is activated. Example: during train joining or splitting procedure, a reset of the cab shall automatically trigger the reset of both train integrity and train length.

Op Req2. The train integrity monitoring function shall be triggered by the confirmation of train length. Disabling of the cab shall trigger the deactivation of the train integrity monitoring function.

Op Req3. All interactions between train Driver/TMS and OTI-L/OTI-I of the train shall be integrated into the ETCS driver interface (DMI) or in the TCMS interface.

Op Req4. Due to the change of train composition a reset of the train length shall be possible by the driver/TMS, triggering a re-evaluation of train integrity and train length.

Op Req5. Necessary interactions of train driver with OTI-L shall be kept to a minimum.

Op Req6. Initialization of OTI-I and OTI-L shall not to be started additionally by the driver.

Op Req7. For OTI-I and OTI-L systems based on wireless solutions, it shall be granted a reliable communication between their constituents.

Op Req8. The solutions associated with the OTI-I and OTI-L functions must be as interoperable as possible, without depending on the technology adopted.

3.2 Train Integrity ORS

Op Req9. Train Integrity information must be transmitted from OTI-I to ETCS OBU.

Op Req10. In case the Train Integrity Value (CONFIRMED; CONFIRMED DR, LOST; UNKNOWN) is to be made visible to the train driver, this shall be implemented on the ETCS DMI.

Op Req11. Any change in Train Integrity Value shall be visible to the train driver, for example by blinking on the DMI where OTI information is displayed. Examples:

- CONFIRMED --> LOST
- UNKNOWN --> LOST
- CONFIRMED --> UNKNOWN,
- UNKNOWN --> CONFIRMED

Note: During the Coupling and Splitting phase the train integrity will certainly be lost but it is information that the driver knows and expects to happen. This should not produce further activity overload.

Op Req12. A loss of train integrity (Value change CONFIRMED --> LOST) shall lead to a warning sound or other measure in order to warn the train driver.

Note: This requirement can be intrusive, especially during Coupling and Joining operations. The advantages and disadvantages of this reporting must be shared by all operators. The final decision will be indicated in future TSI. What is highlighted is the possibility of being able to provide an audible signal.

3.3 TRAIN LENGTH ORS

Op Req13. Train Length information must be transmitted from OTI-L to ETCS OBU.

Op Req14. Train Length (Validated) Value shall be visible to the train driver at any time during operation.

Op Req15. In case the train length determination on the necessary SIL level is provided by technical equipment only, no further action from the train driver shall be required.

Op Req16. In case an interaction with the train driver is necessary for entering or confirmation of train length, this shall be possible using the DMI only.

Op Req17. In case train driver input is used for train length validation, only integer values shall be entered and taken into consideration.

Op Req18. Train length unit shall be metric (SI) metres.

Op Req19. Any interaction regarding train length (e.g. entering train length manually by the driver) shall be limited to the SoM process when the train is standstill.

Op Req20. In case train length data is to be entered by the train driver and the entered value differs from the automatically calculated train length value, this information shall be indicated to the driver.

Note that Op Req19 and Op Req20 are barriers for the hazardous event MMI-5 "Falsification of train integrity confirmation input" considered in Annex A of Subset-091 [1].

4 USER STORIES AND USE CASES

This chapter has the goal to define high level use cases of the train functions in charge of the determination of the train length and of the monitoring of the train integrity, which become a reference for the development of the train architectures in chapter 5 and for new requirements in chapter 7.

The objective of WP19 is to complement the work done in previous projects and therefore only the parts that have added value will be highlighted.

The Use Stories and Use Cases definition is driven by following aspect:

- Constraints given by applicable TSI, Subset-119 [7] and Subset-034 [10] regarding the ETCS OBU TRAIN interfaces;
- Operational requirements in chapter 3
- Coupling, splitting operation, impacting the functions scope of the document.

The attention in WP19 and in the current document is focused on the OTI-I and OTI-L functions and their interactions towards the "surrounding world".

Coming from the deliverable [1] and [2] the finite state machine (FSM) for OTI-I is the one shown in the Figure 2.

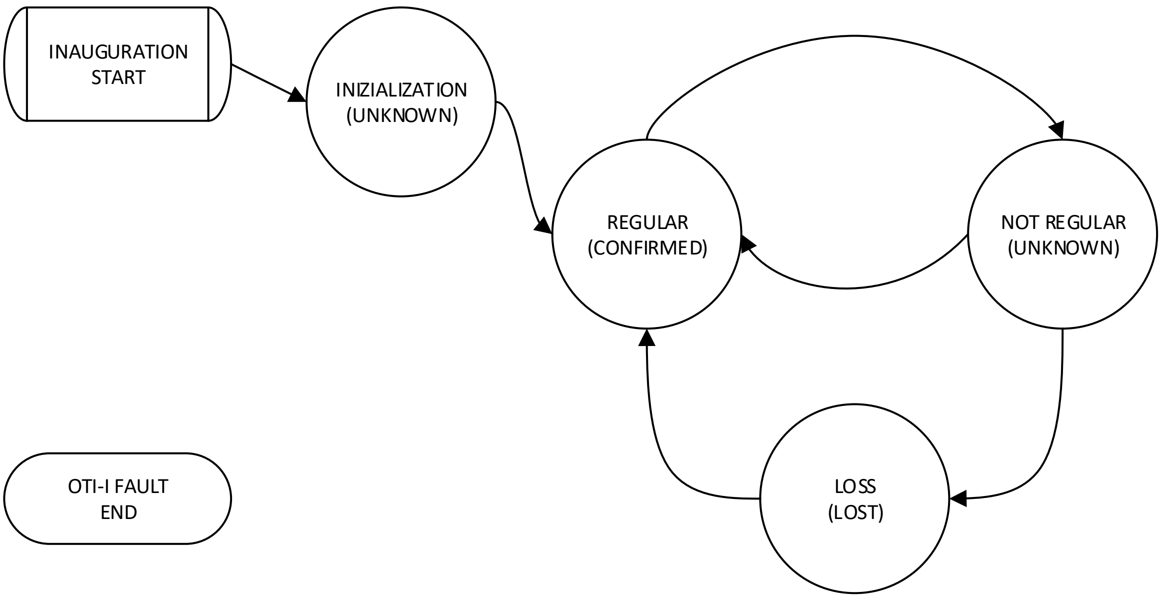

Figure 2: FSM for OTI-I

The OTI-I FSM transitions are reported in Table 2.

Notation “4>” means that condition 4 has to fulfilled to trigger a transition from the state reported in column to the state reported in row and highlighted with the arrow “>”. For each cell, the arrow refers to the direction of the state transition and the number refers to the transition conditions.

States are reported in light blue cells with the following acronyms: I = Initialization, R = Regular, NR = Non-Regular, L = Loss. Transition conditions are described in Table 2.

From PO (Power On) every OTI system goes in Initialization.

I			
1 >	R	< 3	< 5
	2 >	NR	
		4 >	L

Table 2: OTI-I FSM Transitions

The Transition descriptions are reported in Table 3.

Condition	Transition conditions from mode X to mode Y	Entry action in Y state
1	**Transition from I to R** It is verified the train integrity of the train by OTI-I	Send to ETCS the value “Confirmed” as Train Integrity Information.
2	**Transition from R to NR** OTI-I cannot confirm Train Integrity but is making its own assessments or there is no validation of Train Length.	Send to ETCS the value “Unknown” as Train Integrity Information.
3	**Transition from NR to R** I It is verified the train integrity of the train by OTI-I	Send to ETCS the value “Confirmed” as Train Integrity Information.
4	**Transition from NR to L** The train Integrity is declared lost	Send to ETCS the value “Lost” as Train Integrity Information.
5	**Transition from L to R** I It is verified the train integrity of the train by OTI-	Send to ETCS the value “Confirmed” as Train Integrity Information.

Table 3: OTI-I FSM Transitions conditions

Similarly, the MSF for OTI-L is as follows Figure 3.

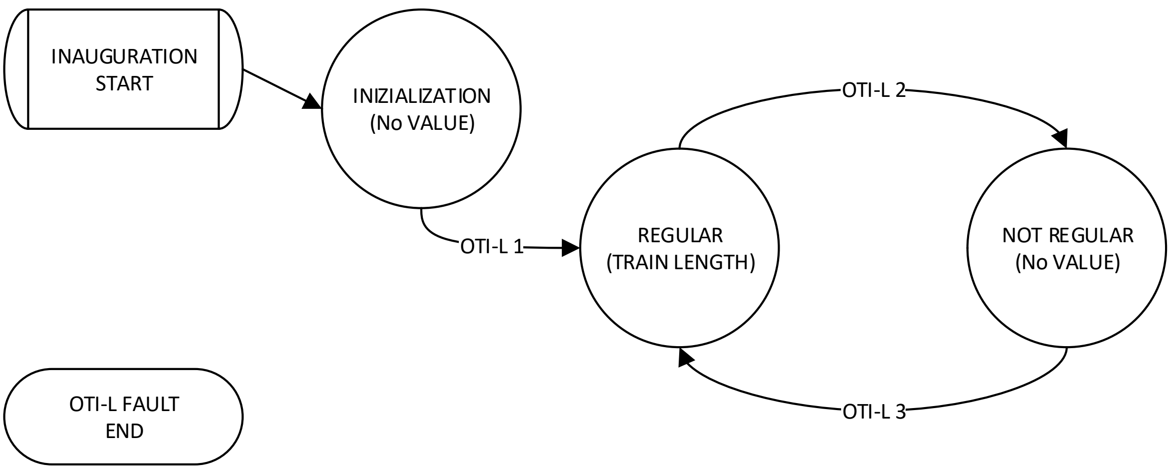

Figure 3: FSM for OTI-L

The OTI-L FSM transitions are reported in Table 4.

I		
1 >	R	< 3
	2 >	NR

Table 4: OTI-L FSM Transitions

The Transition descriptions are reported in Table 5.

Condition	Transition conditions from mode X to mode Y	Entry action in Y state
1	**Transition from I to R** OTI_L is able to determine and validate the Train Length	Send to ETCS the Train Length value
2	**Transition from R to NR** OTI-L isn't able to determine and validate Train Length	Send to ETCS the value 0
3	**Transition from NR to R** OTI_L is able to determine and validate the Train Length	Send to ETCS the Train Length value

Table 5: OTI-L FSM Transitions conditions

In the Use Stories and Use Cases the state and transition described above for OTI-I and OTI-L are used.

4.1 User Stories

This chapter reports the Train Length Determination and Train Integrity Monitoring functions User Stories.

The Actors involved are OTI-I, OTI-L, ETCS OBU, TMS and the Driver.

The role of the TMS is to provide when and if the train composition is needed to the OTI-I and OTI-L functions which eventually make use of it for their own internal processing.

ID	USER STORIES
US1	*The ETCS OBU wants to receive the validated Train Length from the OTI-L if functioning correctly, otherwise the Driver must enter the train length during the ETCS OBU SoM. From Driver point of view no specific interaction with OTI-L are expected*
US 2	*The ETCS OBU wants to receive, periodically, the Train Integrity status from the OTI-I. From Driver point of view no specific interaction with OTI-I are expected*

Table 6: Use Stories

The table shows the user stories that were linked to the operation of the OTI-L and OTI-I. From these the use cases will be generated.

4.2 Use Cases

The use cases reported in this paragraph are those that were considered significant also for clarifying the process followed. The ETCS OBU system sees only one interface from which the information it needs arrives, Train length validated and Train Integrity status.

Below are the use cases analysed:

1. OTI-L and OTI-I function Initialization;
2. Train Length insert by the Driver;
3. Train Integrity confirmed by the Driver;
4. Train Coupling;
5. Train Splitting.

4.2.1 OTI-L and OTI-I function Initialization

Use Case Group	01
Use Case	train length and Train Integrity initialization and activation
UC ID	UC_01_01
Main actor	Driver
Other actors	ETCS OBU, OTI-I, OTI-L
User story	US 1 & US 2
Main goal	Provide Train Length value and Train Integrity status to the ETCS On Board
Assumptions	Train is stand still Train is integer
Precondition	The ETCS OBU is in sleeping mode
Flow of events	1 The Driver turns on the desk key 2 The OTI-L perform internal test 3 The OTI-I performs internal test 4 The OTI-L goes to Regular Mode 5 The OTI-I goes to Regular Mode. 6 The OTI-L evaluate the train length and provide the validated value to ETCS OBU 7 The OTI-I monitors the train integrity and provide the status to ETCS OBU 8 End of use case
Postcondition	The ETCS OBU knows the Train length validated value and the train integrity status
Safety relation	It is a function safety related
Open topics / consideration	

Table 7: UC OTI-L and OTI-I Initialisation and Activation

4.2.2 Train Length inserts by the Driver.

Use Case Group	01
Use Case	train length inserts by the Driver
UC ID	UC_01_02
Main actor	Driver
Other actors	ETCS OBU, OTI-L
User story	US 1
Main goal	Provide Train Length to the ETCS On Board
Assumptions	Train is stand still Tain is Integer
Precondition	The ETCS OBU is in sleeping mode
Flow of events	1 The Driver turns on the desk key 2 The OTI-L perform internal test 3 The OTI-L goes to Not Regular Mode 4 The OTI-L doesn't provide the validated value to ETCS OBU 5 During the SoM the driver doesn't find the Train Length value 6 The Driver in SoM enters the Train Length value 7 End of use case
Postcondition	The ETCS OBU knows the Train length values entered by the Driver
Safety relation	It is a function safety related
Open topics / consideration	

Table 8: UC Train Length insert by the Driver

4.2.3 Train Integrity confirmed by the Driver.

Use Case Group	01
Use Case	Train Integrity confirmed by the Driver
UC ID	UC_01_03
Main actor	Driver
Other actors	ETCS OBU, OTI-I
User story	US 2
Main goal	Provide Train Integrity status to the ETCS On Board
Assumptions	Train is stand still Tain is Integer
Precondition	The ETCS OBU is in sleeping mode
Flow of events	1. The Driver turns on the desk key 2. The OTI-I perform internal test 3. The OTI-I goes to Not Regular Mode 4. The OTI-I goes to Loss Mode 5. The OTI-I provide Train Integrity Status = LOST 6. the Driver recognizes that the train is integer 7. The Driver confirms the integrity and the Train Integrity Status is CONFIRMED DR 8. ETCS OBU use this value 9. End of use case
Postcondition	The ETCS OBU knows that Train Integrity Status is entered by the Driver
Safety relation	It is a function safety related
Open topics / consideration	

Table 9: UC Train Integrity confirmed by the Driver

4.2.4 Train Coupling

Use Case Group	01
Use Case	Train Coupling
UC ID	UC_01_04
Main actor	Driver
Other actors	ETCS OBU, OTI_I, OTI-L
User story	US 1 & US 2
Main goal	Coupling two trains (Train A and Train B) and obtain a new one named Train C. Provide for this new train Train Length validated value and Train Integrity status to the ETCS On Board
Assumptions	There are two trains, Train A and Train B both trains are stand still. The two train are integer. Train A will move to train B The new driving cab of new Train C in on the Train A
Precondition	The ETCS OBU of Train A is in sleeping mode The ETCS OBU of Train B is no power
Flow of events	1. The Driver turns on the desk key on the driving cab of Train A; 2. The OTI-L and OTI-I perform internal test; 3. The OTI-L goes to Regular Mode; 4. The OTI-I goes to Regular Mode; 5. The OTI-L evaluate the train length and provide the validated value to ETCS OBU; 6. The OTI-I monitors the train integrity and provide the status to ETCS OBU; 7. Train A reach Train B; 8. Train A joint Train B; 9. The Driver turn off the desk on the Driving Cab of Train A; 10. The Driver turn on the desk on the Driving Cab of new Train C; 11. The OTI-L and OTI-I perform internal test; 12. The OTI-L goes to Regular Mode; 13. The OTI-I goes to Regular Mode; 14. The OTI-L evaluate the train length and provide the validated value to ETCS OBU; 15. The OTI-I monitors the train integrity and provide the status to ETCS OBU; 16. End of use case
Postcondition	The ETCS OBU knows the Train length validated values and the train integrity status
Safety relation	It is a function safety related
Open topics/consideration	

Table 10: UC train Coupling

4.2.5 Train Splitting

Use Case Group	01
Use Case	Train Coupling
UC ID	UC_01_05
Main actor	Driver
Other actors	ETCS OBU, OTI_I, OTI-L
User story	US 1 & US 2
Main goal	Splitting a Train C in two trains: Train A and Train B. Provide for these new trains (at least for train A) Train Length validated value and Train Integrity status to the ETCS On Board.
Assumptions	There is Train C stand Still. This will be spitted in two trains: Train A and Train B. The new Train A has the driver on board and is the train that leave Train B.
Precondition	The ETCS OBU of Train C is in sleeping mode.
Flow of events	1. The Driver in in the Driving Cab of the new Train A; 2. The Train C is splitted; 3. The Driver turns on the desk key on the driving cab of Train A; 4. The OTI-L and OTI-I perform internal tests; 5. The OTI-L goes to Regular Mode; 6. The OTI-I goes to Regular Mode; 7. The OTI-L evaluate the train length and provide the validated value to ETCS OBU; 8. The OTI-I monitors the train integrity and provide the status to ETCS OBU; 9. End of use case.
Postcondition	The ETCS OBU knows the Train length validated values and the train integrity status
Safety relation	It is a function safety related
Open topics / consideration	

Table 11: UC train Splitting

5 TRAIN INTEGRITY AND TRAIN LENGTH ARCHITECTURE

The chapter 5.1 provides a shortened copy of the concept develop in X2Rail-2 Project as a base and relation for the following chapter 5.2. The introduced OTI Units and OTI Compositions allows to apply existing product classes, OTI-U and OTI-C and its combinations. The objective is to ensure that the combination of OTIs is independent of the technology used. Based on the functional architectures, the train length determination and train integrity monitoring as well as the ETCS and DAC interfaces are described.

5.1 FUNCTIONAL ARCHITECTURE FROM X2RAIL

This section contains the functional architecture specification based on the functional requirement and application scenarios defined in the D4.1 [1] (i.e. passenger scenarios and freight scenarios). Functional architecture described in the following takes into account the most relevant differences among OTI product classes defined D4.1 [1]. As example "wired" or "wireless" remarked in the considered on-board communication networks for classes 1 and 2. Presence of ETCS at both train cabins is considered for class 1. Specific implementation choices for definition of physical architecture are part of product specification and are not the scope of this document.

5.1.1 Functional Architecture for OTI Product Class 1

This section depicts examples referred to OTI Product Class 1 with train integrity criterion consisting in liveliness of the communication between OTI Master at front cabin and OTI Slave at train tail. A configuration for functional architecture is depicted in Figure 4; normally this configuration is applicable to wired composition. Main features for this configuration consist in:

- Fixed train composition;
- ETCS equipment available in front cabin and at train tail (e.g., high speed trains);
- OTI Master and OTI Slave modules implemented as independent (from ETCS) devices, located respectively in:
  - front cabin and at the train tail, both connected to the ETCS equipment (present in Cabin A and in Cabin B);
  - Wired communication network.

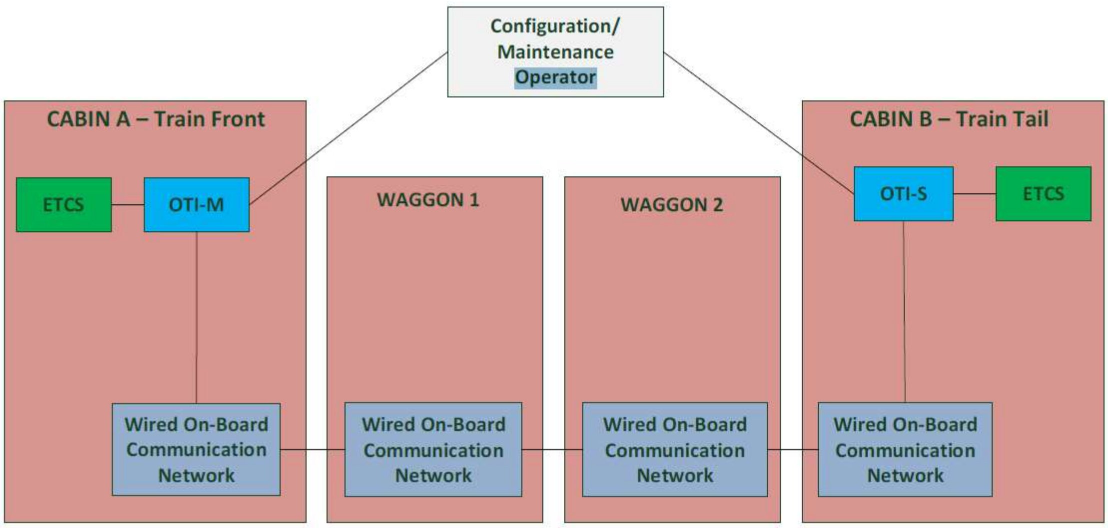

Figure 4: Functional Architecture for Scenario with OTI and ETCS in front and tail

Another configuration for functional architecture of Class 1 (mainly applicable to passenger scenario e.g., urban/suburban) is depicted in Figure 5, referring to central ETCS (e.g. urban/sub-urban). Main features for this configuration consist in:

- Fixed train composition;
- One central ETCS equipment to manage front cabin and train tail;
- OTI Master and OTI Slave modules implemented as independent devices, located respectively in:
  - front cabin and at the train tail, both connected to ETCS equipment. Note that OTI role (Master or Slave) depends on active cabin.
  - Wired communication network

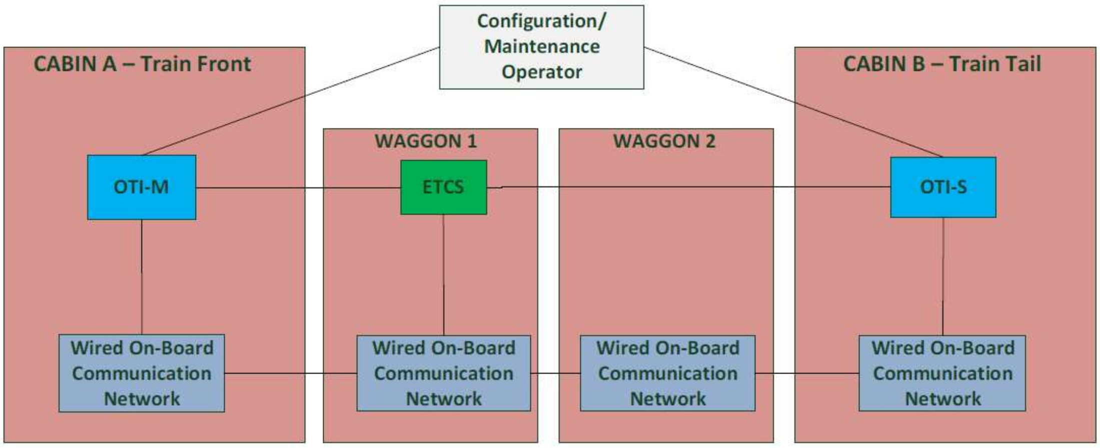

Figure 5: Functional Architecture for Scenario in Central ETCS

An alternative configuration includes peer-to-peer connection between ETCS and OTI-M and between ETCS and OTI-S that can change their role depending on active cabin.

Another configuration for functional architecture in product Class 1 is depicted in Figure 6. Main features for this configuration consist in:

- Fixed train composition;
- ETCS equipment available only in front cabin;
- OTI Master and OTI Slave modules implemented as–independent (from ETCS) devices, located respectively in:
  - front cabin and at train tail. Only OTI Master is connected to ETCS equipment;
  - Wired communication network.

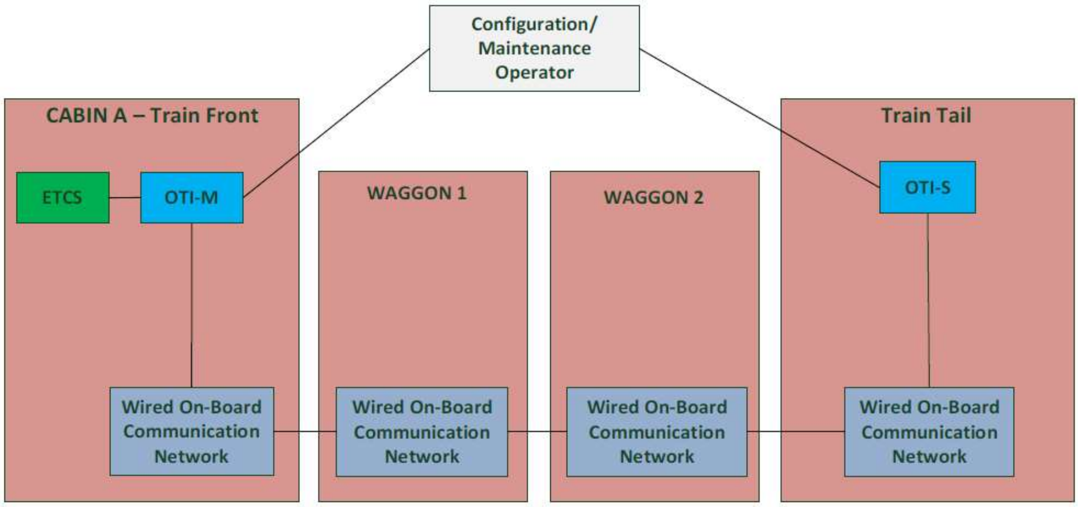

Figure 6: Functional Architecture for Scenario with ETCS only in front cabin

Another configuration for functional architecture in product Class 1 is depicted in Figure 6 referring to high-speed applications with OTI functionality hosted inside ETCS platform, independent from ETCS core. Main features for this configuration consist in:

- Fixed train composition;
- ETCS equipment available in front cabin and at the train tail (e.g., high speed trains);
- OTI Master and OTI Slave modules implemented as SW module hosted inside ETCS platform;
- Wired Communication network.

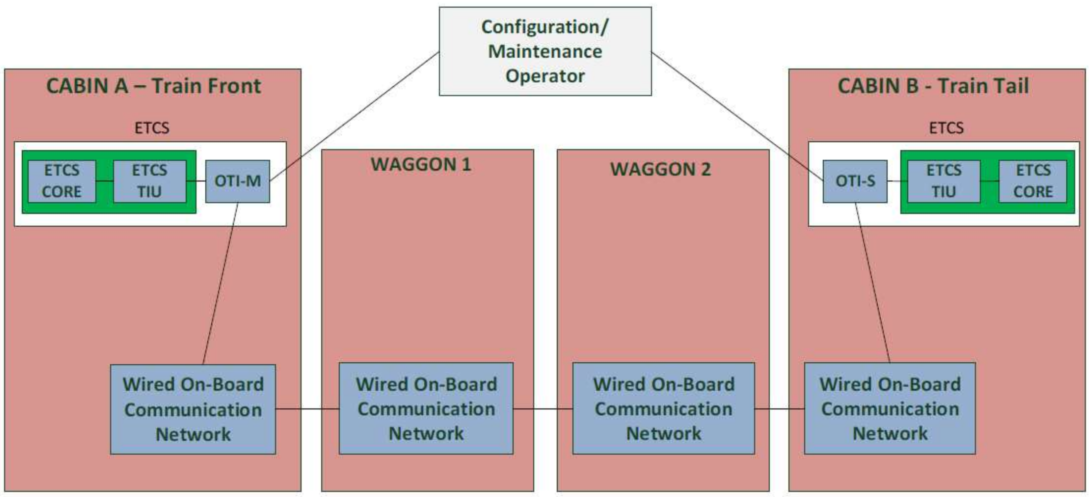

Figure 7: Functional Architecture for Scenario with OTIs hosted in ETCS platform

Another configuration for functional architecture in product Class 1 is depicted in Figure 8 referring to passenger applications with OTI Master functionality hosted inside ETCS platform, independent from ETCS core, and OTI Slave as external device located at train tail. Main features for this configuration consist in:

- Fixed or variable train composition;
- ETCS equipment available only in front cabin;
- OTI Master functionality implemented as SW module hosted inside ETCS platform;

- OTI Slave device implemented as external device located at train tail;
- Wired communication network.

Note: that even though OTI functional module is physically hosted in the ETCS platform, it is independent and external respect to ETCS core. Note that in new generation trains the intentional Joining/Splitting events provided by the rolling stock is equivalent for OTI-M to START command that triggers OTI system reconfiguration for a new train composition. This event avoids further driver involvement to generate manually the START command after completing a new train composition. In this case the functional architecture block diagram includes also interface between OTI and rolling stock.

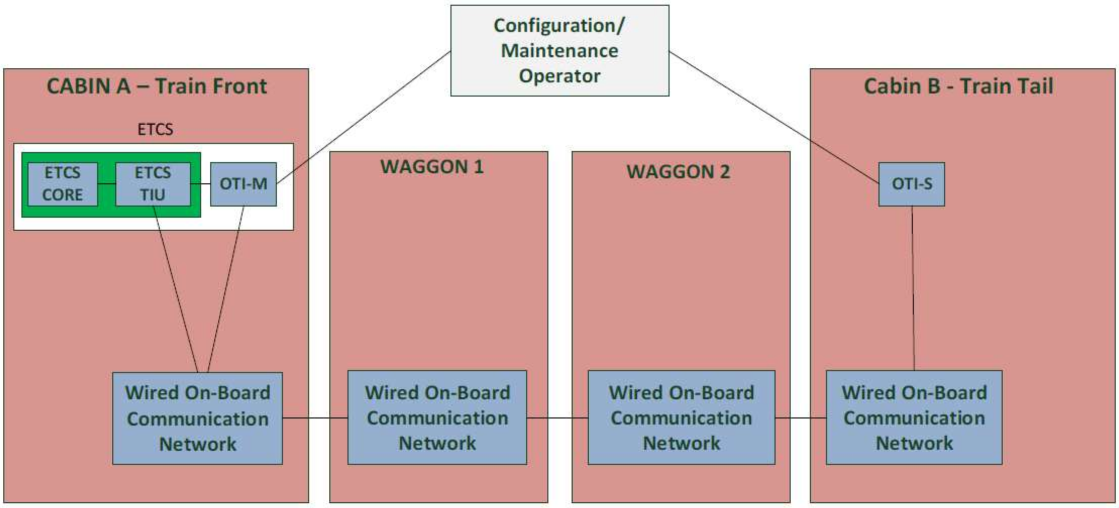

Figure 8: Functional Architecture for Scenario with OTI-M hosted in ETCS platform only in front

5.1.2 Functional Architecture for OTI Product Class 2

This section depicts configurations referred to OTI Product Class 2 with train integrity criterion consisting in comparing kinematic data from OTI Slave at train tail and kinematic data from OTI Master at front cabin: the criterion consists in verifying that the last wagon is regularly advancing in a coherent way respect to the front cabin.

The main feature of this configuration is the wireless on-board communication network; for this reason, is important the completion of the pairing phase, connecting OTI Master to OTI Slave at the tail of the train (OTI Slave Non-Tail can be located in the middle of the train).

A configuration for functional architecture in freight scenarios is depicted in Figure 9. Main features for this configuration consist in:

- Variable train composition;
- Only one ETCS equipment available in the front cabin;
- OTI Master device implemented as external device, located in front cabin and connected to
- ETCS equipment;
- OTI Slave device present at least at train tail or optionally also in all wagons and connected to OTI Master device;
- Wireless communication network.

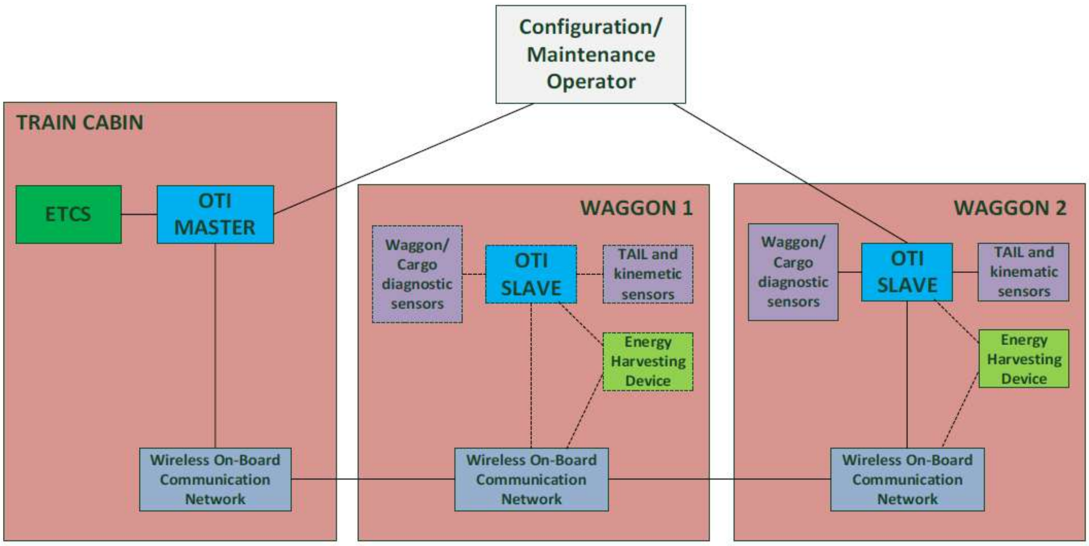

Figure 9: Functional Architecture for Freight Scenario with OTI Product Class 2

Note that in general, the TAIL sensor is an external sensor, however the possibility to integrate TAIL sensor inside OTI is part of product specification phase.

Note that functional architecture in Figure 9 depicts a case with an OTI device for each wagon. Another case for consists in OTI Slave device only at train tail.

5.1.3 Functional Architecture for OTI Product Class 3

On-board configuration Product class 3 is composed of an OTI device in front cabin with Master role connected to ETCS and an OTI device in each wagon with Slave role. OTI devices communicate over a wireless on-board network. In this case, the train integrity criterion consists in communication liveliness and separation detection between adjacent wagons.

Network topology discovery techniques are used to determine train composition both for train integrity monitoring and train length determination. Interaction with trackside is considered to mitigate the risk of errors in train composition determination that would results in partial monitoring of train integrity (e.g. OTI fault in an intermediate wagon would prevent discovering the subsequent wagons).

For this reason, the train composition is also acquired by trackside and compared with discovered train composition with confirmation procedure that also involves the train driver on a dedicated dashboard. With the aim of reducing driver intervention, in R2DATO, this behaviour shall be reviewed.

An example for functional architecture in OTI Product Class 3 is depicted in Figure 10. Main features for this configuration consist in:

- Variable train composition;
- Only one ETCS equipment available in the front cabin;
- Wireless on-board communication network;
- OTI Master device implemented as external device, located in front cabin and connected to ETCS equipment;
- OTI Slave devices present in all wagons and connected to OTI Master device;
- Separation sensor for each wagon to detect separation between adjacent wagons.

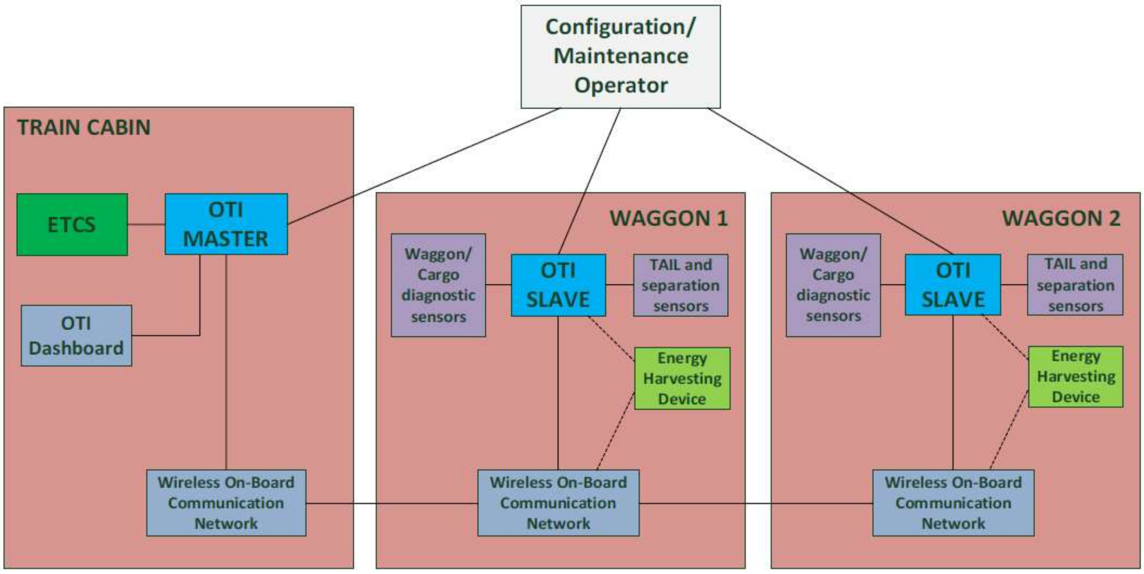

Figure 10: Functional Architecture for OTI Product Class 3

5.1.4 Relations between Train Integrity and Train Length

This section highlights the interaction between the train integrity monitoring function such as OTI-I and the train length determination function such as OTI-L. These two functions interact in the following three aspects:

- OTI-L provides the Train Length to ETCS and to OTI-I;
- OTI-I may use Train Length from OTI-L as input for Train Integrity criterion (e.g., OTI product Class 2);
- OTI-I provides Train Integrity information after that OTI-L provided Train Length (i.e., Train Length is used as trigger event to enable OTI-I communication to ETCS).

These relationships will then be considered in the following steps.

5.2 Functional Architecture by OTI Unit and OTI Composition Concept

5.2.1 Consolidation from X2Rail

From the activities conducted in WP19, points emerged reported in this paragraph connected to the consolidation of what comes from the X2Rail-2 and X2Rail-4 projects.

In the X2Rail-2 architecture [1] the OTI-Dashboard is foreseen to control the train integrity and train length determination and to show status information. From today´s perspective, the Dashboard can be a part of the DMI or a fully automatic function of the train control system without additional driver actions.

The architectures of the OTI Product Classes 1, 2 and 3 considers in each case a device at the front and tail as OTI-Master or OTI-Slave. This architecture may be valid, but it should be questioned.

Under today´s perspective, fixed compositions like XMU´s may provide the OTI data by implemented train control system without any additional OTI devices at each Wagon. For flexible compositions, it may be assumed that the DAC activities provides installed devices or electrical loops to detect the Train Integrity from each Unit. It should be considered that the mode supervised manoeuvring with principle of cab anywhere is covered by this architecture and the OTI-master is not always the front of the train.

The backward compatibility according to chapter 6.4 “Functional Architecture for ETCS backward compatibility” [1] needs to be checked against actual TSI CCS specifications. The generic interfaces according to Subset-034 [1] and Subset-119 [1] have to be considered.

The backward compatibility also applies to the relationship between Train Integrity and Train Length. Fixed compositions and flexible compositions equipped with internal devices capable of automatically determining integrity and length, can be generalized in the cab anywhere principle.

However, when we are dealing with old generation trains belonging to the Class 2, it becomes necessary to use the OTI-Master and OTI-Slave present on head and tail architecture. In this situation the determination of Train Integrity depends on the knowledge of Train Length coming from an external system (compared with ETCS), adopting mitigation mechanism to achieve the required safety level.

5.2.2 OTI Unit Concept

Derived from the X2Rail Architectures, it shall be considered that the OTI functions can be provided by independent OTI Units. A Unit can be a single wagon, a locomotive, or a permanently fixed composition like an XMU. The OTI Unit can be realized and represented by a physical single device, or a function implemented by another computer, e.g. TCMS or EVC.

The implementation must comply with the safety requirements. Each OTI Unit has a unique identifier and shall handover the data for train integrity as well as for train length in a certain manner and defined dataset.

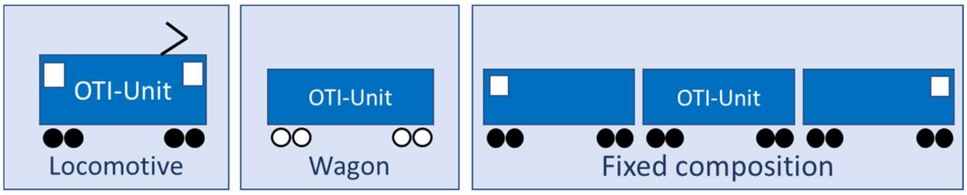

Figure 11: Examples for OTI Units

In general, OTI Units can operate as Master or Slave. It is possible to implement OTI Units that can operate only as Slave.

5.2.3 OTI Composition Concept

For the functional aspect of operation, all OTI Units together compose an OTI Composition. The smallest OTI Composition is a single OTI Unit like a single locomotive, wagon or a permanently fixed composition like an XMU.

A composition remains connected as long as it is active or in standby and no change of the coupler is detected. Within this composition, the OTI Unit related to the active cab is automatically assigned to be the Master and all others are OTI Unit Slaves.

There will be no restriction how to arrange the composition and on which position the active cab is. Even the driving direction is independent from the active cab.

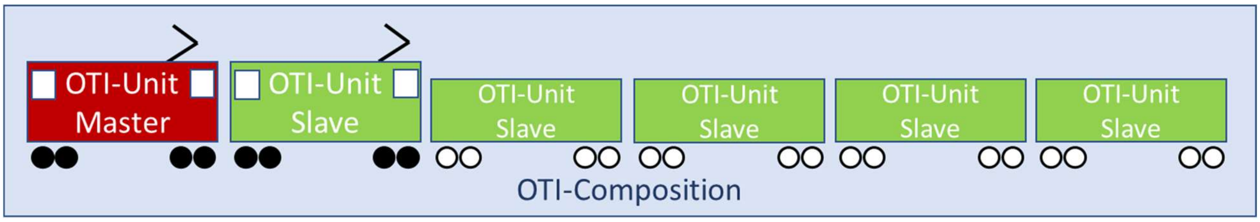

Figure 12: Example for coupled OTI Units as OTI Composition

The OTI Unit Master of the OTI Composition represents the complete OTI Composition and collects the required data for train length from all connected OTI Units Slaves, observes the train Integrity and fulfil the availability, performance and safety requirements for the whole composition.

In addition to permanently fixed compositions, which are also defined as OTI Units, any solution from Product Class 1, 2, 3 (Product Class X) can be represented as OTI Composition and used for XMU´s, permanently fixed or semi-fixed compositions which are equipped with a specific supplier solution with individual internal interfaces, devices and architecture. This OTI Composition Product Class X is a black box because the OTI Composition Concept has not requirement against internal solutions.

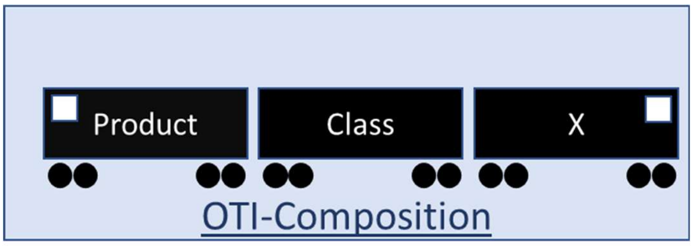

Figure 13: OTI Composition Black Box for Product Class X

Similar to the function "cold movement detection", the OTI Composition is able to detect changes in the composition. This function can help to reduce the effort for the "start of mission" especially when a fixed composition is only in parking mode, e.g., standing on a platform for a certain time, and the operational procedures does not require any additional checks like full brake test and so on.

5.2.4 OTI Composition Coupler Concept

OTI Compositions can be used in single operation or coupled to other OTI Compositions. Only the end of the OTI Composition needs to be considered. Intermediate couplers of the composition remain unconsidered. A coupled composition must be either active, will be activated by Joining or is in standby. There are two options of Coupling OTI Compositions however the composition itself is composed of.

1. The coupler of the OTI Composition has a specific supplier solution and multi-traction is only foreseen for the same or similar car-type.
2. The coupler of the OTI Composition is equipped with DAC (preferred) or standardized data-cable and connector like UIC 558 or UIC-IT.

When the Coupling procedure is completed, the OTI Composition related to the active cab becomes automatically the OTI Composition Master and all others become OTI Composition Slaves. This allows infinite variants of Joining and might covers all possible use cases for operational or technical reasons.

5.2.5 OTI Composition Coupling Examples

The following figures presents some of the conceivable solutions. To simplify the shown examples, the active cab with the OTI Composition Master is always in driving direction.

A towing-locomotive needs to be coupled to another active OTI Composition to vacate the track. Both OTI Compositions have the same DAC or standardized data cable.

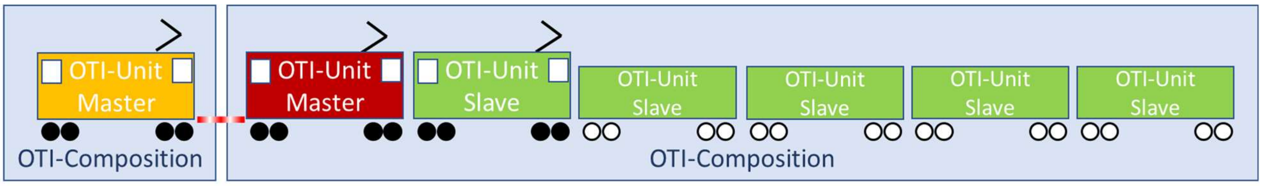

Figure 14: Coupling procedure between a towing locomotive and an OTI Composition

The yellow towing locomotive becomes the OTI Composition Master and the towed train the OTI Composition Slave. The OTI Unit Master of the towed train represents the OTI Composition Slave for collecting and providing all train data of its composition.

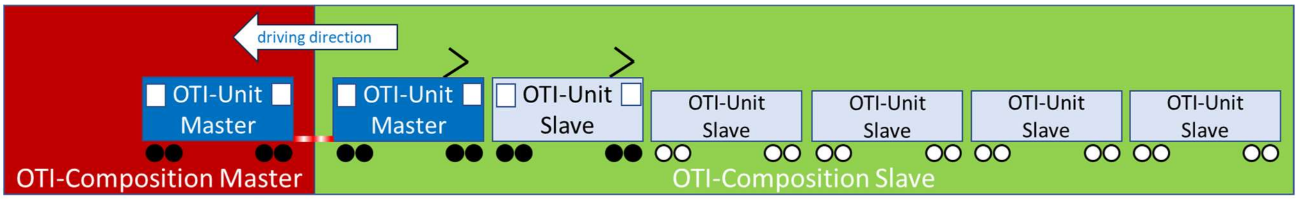

Figure 15: Coupled OTI Compositions in towing case

Another application can be the Joining of XMU´s for technical or operational reasons as shown in the following figures. The OTI Composition, related to the active cab, becomes the Master and the other is the Slave. In this case, there are different options possible. Either all coupled compositions are equipped with the DAC or specific supplier solution and all compositions are composed of OTI Units or Product Class X.

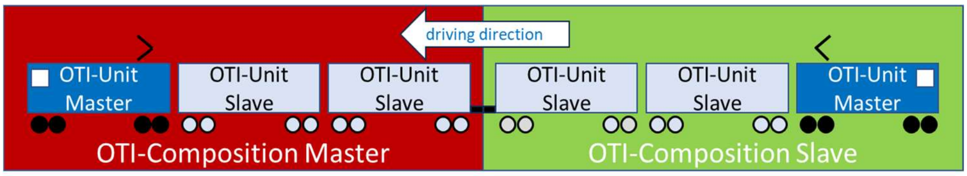

Figure 16: Coupled XMU OTI Compositions - OTI Units

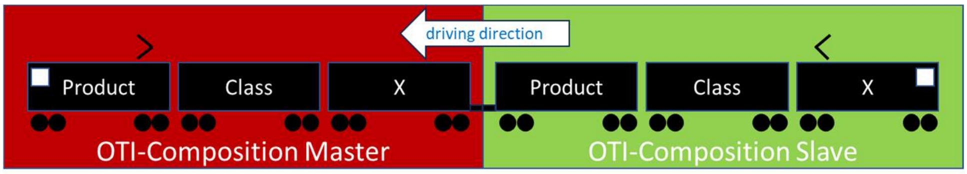

Figure 17: Coupled XMU OTI Compositions - Product Class X

A Coupling between OTI Compositions consists of OTI Units and Product Class X shall be possible when they are equipped with the DAC or a standard data cable. The application is conceivable for fixed wagon or wagon-locomotive compositions which needs to be coupled to other locomotives.

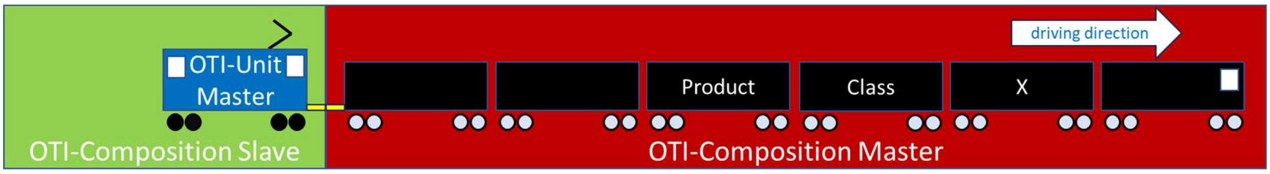

Figure 18: Coupled OTI Composition - OTI Unit and Product Class X

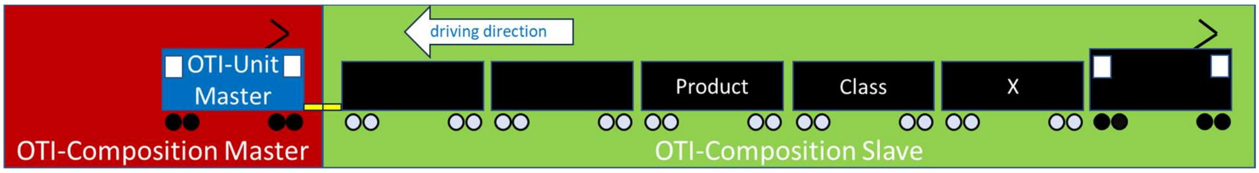

Figure 19: Coupled OTI Composition - OTI Unit and Product Class X

As an outlook, OTI Units shall be equipped with the DAC to become individual OTI Compositions which can be easily implemented in compositions for all conceivable use cases. Each of those Compositions shall be able to be coupled to other cars especially when broken-down vehicles needs to be easily towed to vacate the track.

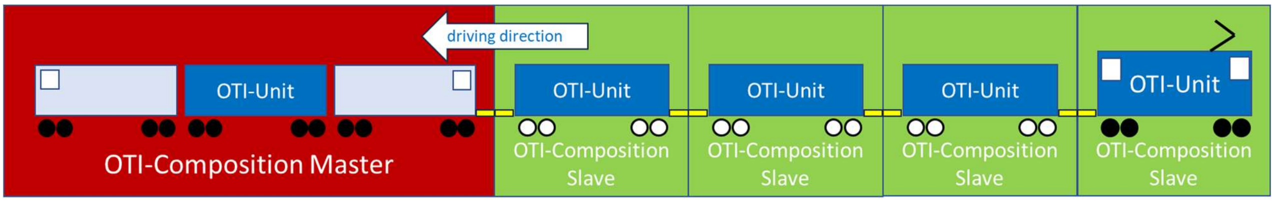

Figure 20: Coupled OTI Composition - OTI Composition with DAC

5.3 Train Length Determination and Train Integrity monitoring

Chapters provides a shortened overview of the result from X2Rails projects as base for the R2DATO WP19 architecture.

5.3.1 Architecture

This section depicts the functional architecture related to the Train Length Determination and Train Integrity Monitoring.

The starting point is the purpose of determining the train length: this information needs to be transmitted to ETCS (as a part of Train Data entry) only once, after the composition of the train has been checked.

As defined in Subset-026 [1], there are two inputs that the OTI shall send to ETCS:

- Train integrity status information
- Train length value information

More details about the interface are provided in Subset-034 [1] (FIS) and Subset-119 [1] (FFFIS). In particular the following signals are defined:

- "TR_OBU_TrainIntegrity" is the train integrity status (confirmed / lost / unknown)
- "TR_OBU_TrainLength" is the nominal train length
- "TR_OBU_L_CONSISTFRONTCABAMAX" is the maximum length on the side of the engine corresponding to Cab A (considering the mechanical Coupling play)
- "TR_OBU_L_CONSISTFRONTCABAMIN" is the corresponding minimum length

- “TR_OBU_L_CONSISTFRONTCABANOM” is the corresponding nominal length
- “TR_OBU_L_CONSISTREARCABAMAX” is the maximum length on the side of the engine opposite to Cab A (considering the mechanical coupler play)
- “TR_OBU_L_CONSISTREARCABAMIN” is the corresponding minimum length
- “TR_OBU_L_CONSISTREARCABANOM” is the corresponding nominal length

Referring to the result from X2Rail, the “nominal” train length, defined as the sum of the length of each unit in the train composition is known for OTI product Class 1 and product Class 3, by definition (fixed composition or automatic Coupling / DAC).

For the OTI product Class 2, this “nominal” train length shall be provided by an external system (or by the driver) or an external system shall provide the train composition. This length must be checked if it has not the requested safety level; using trackside interaction is a possible solution.

After having sent the train length information to ETCS, only the train integrity status (TR_OBU_TrainIntegrity) is relevant to ETCS while driving. The “safe” train length needed for communication with the RBC is calculated by ETCS OBU using the length information sent by OTI and the travelled distance from the last tail position detected with confirmed integrity.

Referring to the result from X2Rail, the train integrity determination during the movement of the train does not need to recalculate train length for OTI product Class 1 and OTI product Class 3; for OTI product Class 2, to evaluate the coherent movement of the head and of the tail and consequently the train integrity, the length must be recalculated, while the train is moving, using kinematics data from head and tail.

5.3.2 Application to OTI Composition

As for Train Integrity, also Train Length shall be provided in OTI Compositions. The starting point for Train Length definition is the composition itself; any change detected shall be the trigger to redefine the length and the train integrity. For this reason, OTI product Class 1, Class 2 and Class 3 can be translated to OTI composition.

What it is important to point out is the relation between Train Integrity and Train Length, which is the subject of the next section.

In the next section also the Coupling of OTI Compositions and the collection of single OTI Composition data shall be considered.

5.3.3 Sequence Diagrams

In the following part of this document, sequence diagrams concerning link between Train Integrity and Train Length (and between functionality of OTI-I and OTI-L) are reported. In this document the distinction between basic ETCS and advanced ETCS is not considered as in X2Rail.

These sequence diagrams are applicable to all the previous functional architectures, being defined for high level functionalities.

In Figure 21 is reported the sequence diagram for a composition in which Train Length is a variable that must be determined starting from composition and must be sent to ETCS (“Nominal” Train Length). In this case, Train Integrity can be determined without using Train Length determined from OTI-L (e.g., in X2Rail product Class 1 and product class 3).

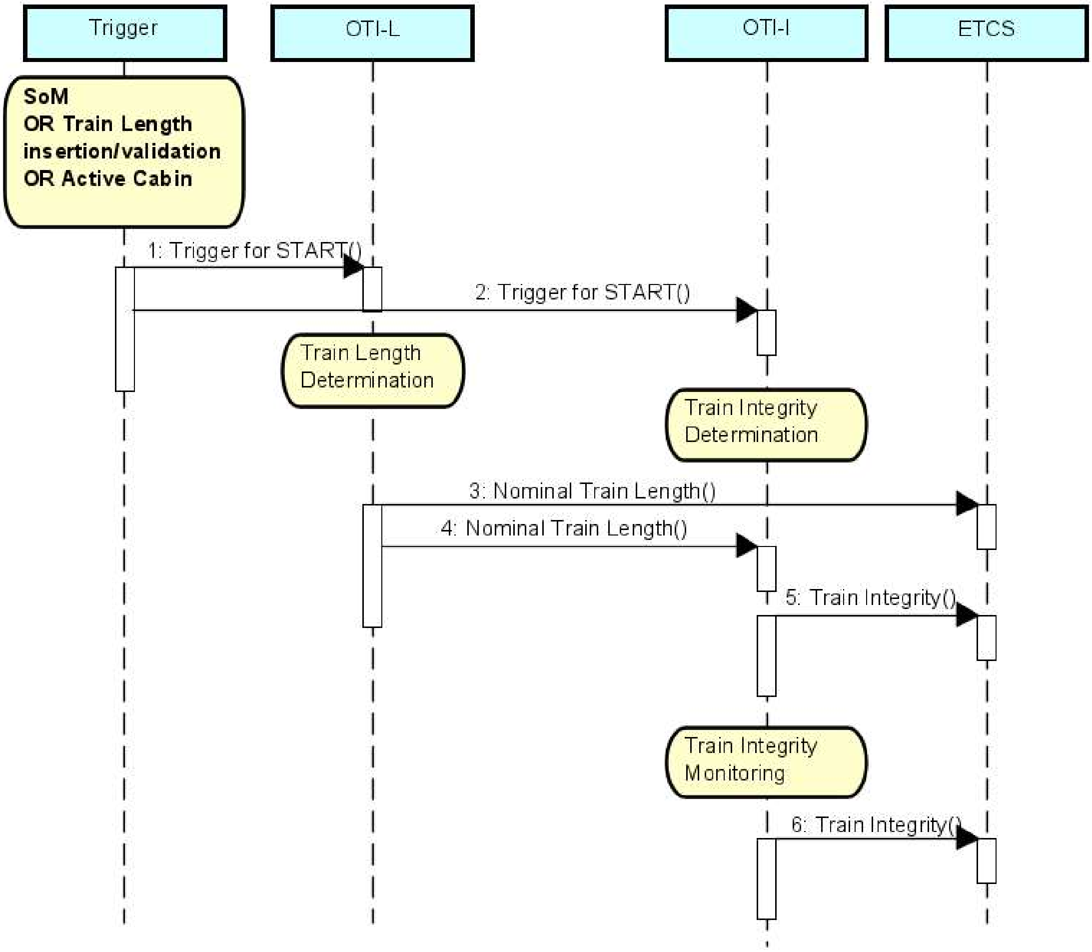

Figure 21: Sequence diagram Train Integrity defined without using Train Length

In Figure 22 is reported the analogue sequence diagram for a similar case but in this case, Train Integrity can be determined using Train Length determined from OTI-L (e.g., in X2Rail product Class 2).

In this case, there is the possibility that the Train Length, coming from composition, could have not the requested safety level (the main case is if entering in Level 3 ERTMS/ETCS). In this case OTI-L must upgrade the safety level using internal function depending on the implemented technical solution (e.g., trackside interaction).

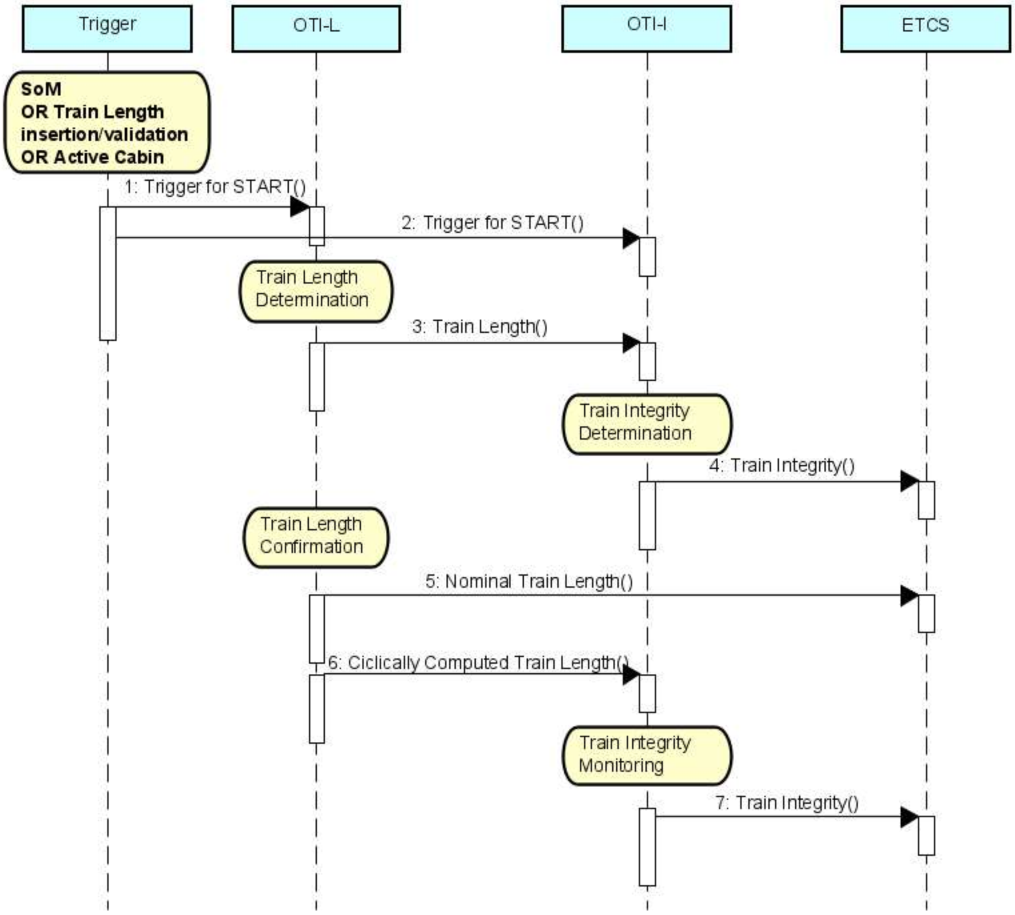

Figure 22: Sequence diagram Train Integrity defined using Train Length

The necessity to confirm Train Length, using trackside interaction (e.g., balise) can be performed only on the initial moving of the train; for this reason, it's necessary that the train must have permission to move (exclusively on a Level 1 or Level 2). After the confirmation of the Train Length, the monitoring of integrity starts.

The difference with the previous case, is that the Train Length is used to determine integrity; this is the case of wireless communication network, for which the only liveliness of communication between OTI Master and tail OTI Slave is not sufficient to determine if the train is integer.

In this section the Joining of two OTI Compositions is taken in consideration. It's important to point out that the scope of R2DATO is to harmonize OTI product provided by different supplier; each OTI Composition involved has defined architecture and knows his own total length and his own driving direction.

As described in the previous section of OTI Compositions, the most general case to consider in the Coupling diagram is the “CAB anywhere”; all the architectures defined in X2Rail and OTI Composition chapter can be derived from it.

Calculating the length of the consist by Joining of minimum two OTI Composition

The representing Unit of the composition knows the total length of the composition, the driving direction and the extension of the composition in each direction, starting from the OTI Composition Master.

When OTI Compositions are coupled, the representing OTI Composition Units knows their orientation and the coupled side and will calculate the total train length based on the provided data.

The more general situation is represented by the “Cab Anyway” composition.

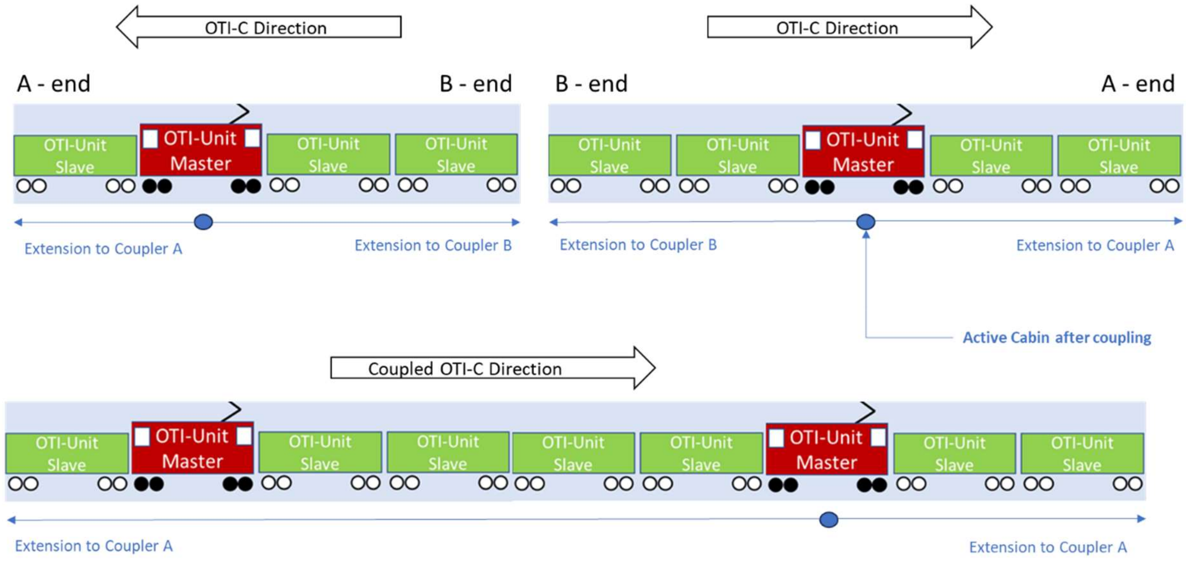

Figure 23:Train Length for Cab Anyway Composition Coupling

In Figure 24, a simplified sequence diagram is reported.

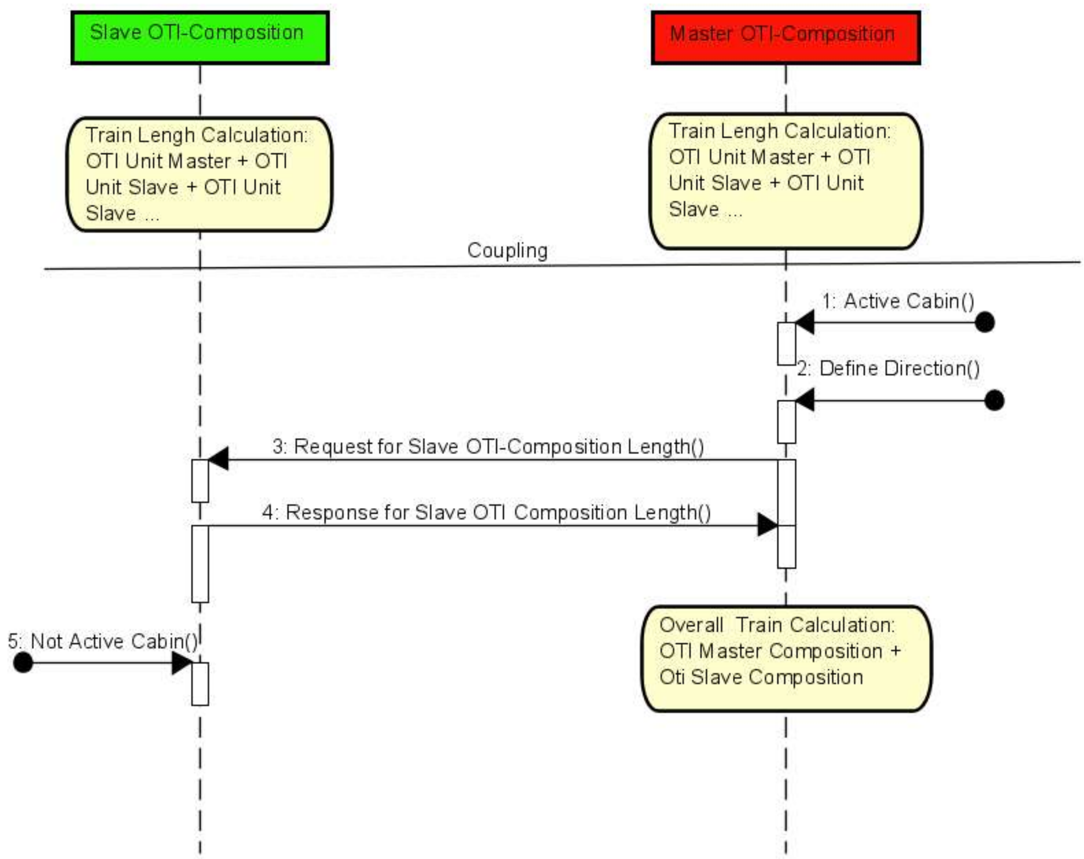

Figure 24: Simplified sequence diagram for a Coupling of two OTI Compositions

6 OTI INTERFACES

This chapter describes the interfaces to the other modules of the Train Integrity and Train Length functions with respect to the ETCS system, this interaction has already been addressed in X2Rail-4 and is an addition the interaction with the DAC system. The interfaces specified in Subset-119 [1] are also reported for clarity.

6.1 INPUTS FROM TSI (SUBSET 119)

Inside the current TSI the Subset-119 [7] represents a fundamental reference to describe the interfacing between the OTI part and the ETCS on-board system. This does not exclude the possibility of creating ETCS system solutions that implement OTI functions internally.

For the ERTMS/ETCS on-board only the serial interface is mandatory. Also wired interface is possible as optional solution. Here the focus is on the mandatory ones. The wired interface is foreseen for the old stile train.

6.1.1 Serial Architectures

There are two possible architectures for the transmission of information via a serial bus – Architecture A) and B). Both architectures are fit for the transmission of safety related and non-safety related information. It is up to the train integrator to choose the adequate architecture.

Architecture A)

This architecture allows the use of hardware which is not able to implement requirements defined in [8]necessary for safety related communication.

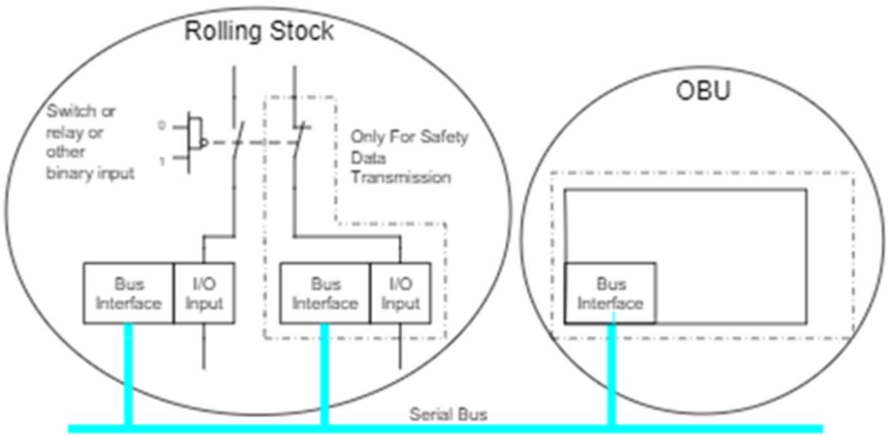

Figure 25: Serial Interface Architecture A)

Architecture B)

This architecture allows the use of hardware which is able to implement requirements defined in [8] necessary for safety related communication.

The architecture allows the transmission of both non-safety related and safety related information. Using safety devices the TFR achievable depends on the Rolling Stock design (Hardware and software).

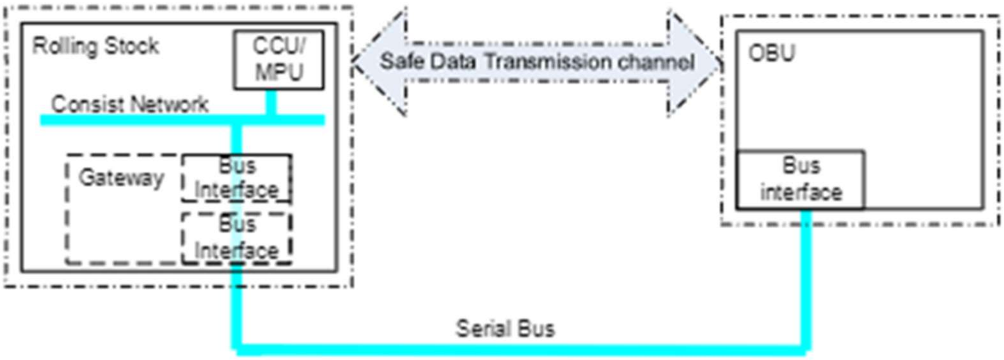

Figure 26: Serial Interface Architecture B)

When using Architecture B) safe data transmission shall be applied according to [9] , Appendix B when the required safety integrity level of certain functionality cannot be fulfilled with safety integrity level provided by the serial bus transmission.

6.1.2 Functional Interface

The following table reports the meaning of the information exchange from OTI to ETCS for the **Train Integrity** information for transfer the information from OTI to ETCS On Board.

T_TRI_S1_N/TR_OBU_TrainIntegrity_S1	T_TRI_S1_I/TR_OBU_TrainIntegrity_S1_Not	T_TRI_S2_N/TR_OBU_TrainIntegrity_S2	T_TRI_S2_I/TR_OBU_TrainIntegrity_S2_Not	Meaning
0	0	0	0	Invalid
0	0	0	1	Invalid
0	0	1	0	Invalid
0	0	1	1	Invalid
0	1	0	0	Invalid
0	1	0	1	Train Integrity Lost
0	1	1	0	Train integrity status unknown
0	1	1	1	Invalid
1	0	0	0	Invalid
1	0	0	1	Invalid
1	0	1	0	Train integrity confirmed
1	0	1	1	Invalid
1	1	0	0	Invalid
1	1	0	1	Invalid
1	1	1	0	Invalid
1	1	1	1	Invalid

Table 12: Coding for Train Integrity

Regarding the **Train Length** is using an UNSIGNED16 variable where only the less 12 significant bits are used. This value expresses the length in meters. The remaining bit must be set to 0.

6.2 ETCS INTERFACE

The output of the ETCS On Board versus the RBC can be summarize in:

The train integrity information reported to the RBC shall consist of:

a. Train integrity status information:
   - No train integrity information
   - Train integrity confirmed by external source
   - Train integrity confirmed by driver
   - Train integrity lost
b. Confirmed train length information (only available when train integrity confirmation is reported).

The confirmed train length information shall represent the distance between the min safe rear end at the time the train was last known to be integer and the estimated position of the train front at the time when the train integrity information is sent to the RBC

In the WP19 activities was recognize that are necessary additional information for simplify the interaction from ETCS-OB and OTI systems.

From OTI to ETCS-OB Diagnostic information:

- OTI-I system status
- OTI-L system status

This information can help the interaction and avoid from ETCS-OBU side to wait for long time the information expected from OTI systems.

For the OTI-I could be insert in the table when all the bits are at 1 the meaning could be OTI-I out of order. For the OTI-L could be a codification of all the bits to 1 that means OTI-L out of order.

To prevent the ETCS-OBU system from receiving unstable information, for example a train is being composed and both the Train Integrity and the Train Length change until the composition is successfully completed, the assumption made is that the Start Of Mission is performed by the Driver only when the train is in a stable condition. Currently, it is envisaged that the management of this information will be open-loop.

To achieve closed loop management, especially when there will be automatic guidance, there must be a trigger that indicates when the configuration is considered stable.

This shall be resolved at the train level, but the ETCS-OBU system could be provided with a value that makes it clear that the train is forming and is not yet finished. For example, the end of the train is not identified in a stable way.

This information could be transferred to the ETCS-OBU with dedicated coding. This information is valid only if the train is stand still.

For the OTI-I could be insert in the table when all the bits are at 0 the meaning could be OTI-I is waiting to have a stable condition. For the OTI-L could be a codification of all the bits to 0 that means OTI-L length will be elaborate at the end of the operation.

6.3 OTI - TMS INTERFACE

The interaction between OTI and TMS shall be necessary when the OTI Composition communication network needs to receive the train composition and the information about the length of wagons. Receiving the train composition is also necessary to compare the composition discovered at on-board level with the planning data.

The information given by TMS are of different kind, the only important for OTI is the **Train Composition**.

The message exchanges between OTI and TMS follows the TMS Integration layer specification included in [1] of X2RAIL-2 project.

6.4 OTI COMPOSITION INTERFACE

Considering that each OTI-C must manage the train integrity and the determination of the train length internally, and considering that another OTI-C has no visibility within the managed composition, the interfacing between two OTI-Cs must contain information complete and definitive.

From a functional point of view, an OTI-C Slave must provide the OTI-C Master with at least this information:

- Train integrity status
- Trail length validated.
- OTI-C status
- OTI-C identifier

The periodicity for which this information must be updated is linked to safety aspects and functional aspects.

The safety aspects concern the concept that information is not frozen, while the functional ones depend on how often the Train Integrity information must be renewed towards the trackside system.

If we assume that the position report from the EVC to the RBC is sent every three seconds then the rate of information exchange between two OTI-Cs must certainly be lower.

In this phase of the project inside the Work Package 19 is defining the basis of the solution that will be developed inside the Work Package 20.

Another aspect that needs to be clarified is the confirmation of continuity (train integrity) between two OTI-Cs.

The interfacing must allow us to recognize whether two OTI-Cs are correctly joined or not.

The requirements that derive from this aspect are:

IF-Req 1. OTI-C must provide Train Integrity information with the same SIL as a generic OTI Master

IF-Req 2. OTI-C must provide Train Length value with the same SIL as a generic OTI Master

IF-Req 3. OTI-C must provide its own state which will be the result of the state of the connected OTI-Cs. All it takes is for just one OTI-C to be faulty and the overall state will be Fault.

6.5 DAC INTERFACE

The DAC System, developed in FP5, is expected to provide Train Integrity and train length information.

In general, the ETCS system expects to receive these two families of information:

- Train length value that shall be of a quality corresponding with at least SIL2 but should be SIL4 if possible.
- Train Integrity information sent in the position report shall be provided by external source with at least SIL2 quality.

In the best case that the DAC system provides these with the required Safety Integrity Level then the OTI function is transparent and must not add anything to what is already reported by the DAC system.

The following figure reports a first functional DAC solution. Considering what is indicated in the figure, the output provided by the blue box towards the ERTMS/ETCS on-board system is perfectly equivalent to that expected from a generic OTI Master.

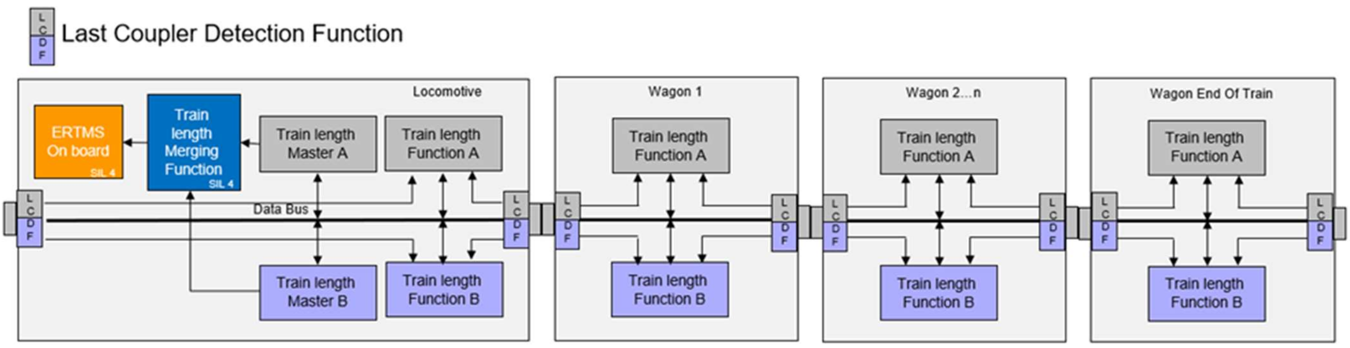

Figure 27: Preliminary Functional DAC Solution

However, if the output of the DAC system isn't in line the two requests, for example for the train length two Train Length values are reported with an associated SIL equal to 2, then in this scenario the OTI part must carry out analyses to produce an output towards the system ETCS On Board eligible for requests.

In the second case, to reach the required target, the OTI system following a Hazard risk analysis will certainly have to be able to perform additional tests so that the combination of two SIL2 inputs can produce a SIL4 output.

This is a topic of interaction between FP2 WP19, FP5 and also System Pillar.

Interactions between the parties involved in the different projects have begun. When there is a consolidated description of the data sent by the DAC system and the associated SIL level, further considerations can be made.

There are certain activities required to realize the solution. The wired interface of the DAC needs to be aligned with the requirements to transfer the data for train integrity and train length. A standard interface between the OTI-functions, provided by the OTI Composition needs to be defined on the FFIS or FFFIS layer.

7 TRAIN INTEGRITY AND TRAIN LENGTH REQUIREMENTS

This section starts from the X2Rail Requirements [1], adding to them the new functional definition related to OTI Composition concept and including the Train Length as a validated value to transmit to ETCS. In addition, requirements resulting from the TSI CCS 2023 v4.0 [13] regarding train length and train integrity are added.

Specifically, the interaction of the OTI Unit with DAC and TMS are inserted. The interactions between OTI Compositions are also considered.

For the Train Integrity and Train Length Requirements, it is assumed that the involved actors are:

- OTI Unit
- TMS
- DAC
- ETCS
- TIU

The OTI system consists of the train's OTI Unit (OTI-Master and OTI-Slave) and associated components. The OTI implements the functions train length determination (OTI-L) and train integrity monitoring (OTI-I).

Fun. Req 1. At least one OTI Unit shall be associated with each consist.

Fun. Req 2. Each OTI Unit shall, as a minimum, provide the integrity status and length of the associated consist to the OTI Master.

Fun. Req 3. One or multiple OTI Unit shall be able to be combined to form an OTI Composition for a consist or train.

Fun. Req 4. An OTI Composition shall, as a minimum, provide the integrity status and length of its associated OTI Unit to other OTI Compositions.

Fun. Req 5. The interface between the OTI system to the ETCS OBU shall be realized according to the TSI CCS 2023 (version 4.0) and especially with regard to the train interface specified Subset-034 [1] Train Interface FIS and Subset-119 [1] Train Interface FFIS)

OTI system self-test function:

Non-Fun. Req 1. All faults of the OTI system shall be detected, within 24 hours at the latest. (Subset-120 [1] FFFIS TI – Safety-related requirements 2.1.6.3 Train Integrity 2.1.6.3.3.5 FDT for the signals = 24 h)

Note: To achieve the safety targets of the TIMS, detection of a malfunction of the OTI system by the self-test function is necessary within a dormancy or latency period of 24 hours at the maximum.

Non-Fun. Req 2. The overall train integrity monitoring function shall achieve at least SIL 2. (Subset-091 [1] 9.6. EXT_SR08)

Info: The occurrence of a loss of train integrity (Q_INTEGRITY) shall not be more frequent than with a THR of <= 2.61*10-6/h (SIL2) (for passenger trains). (Subset-091 [1] 10.3.2.10 Max. unexpected loss of train integrity)

Note: For freight trains, the THR shall be <=6.98*10-5/h [1], assuming screw-hook coupler for freight trains. This value may change with the introduction of the DAC.

Info: The resulting occurrence of an erroneous confirmation of the train integrity (Q_INTEGRITY), in case of a loss of train integrity, shall not be more frequent than with a THR of <= 10-9/h (SIL4).

Note: This is in accordance with the safety requirement of L_TRAININT (Subset-091 9.6. EXT_SR06 [1])

Fun. Req 6. The OTI system shall detect intended changes to the train configuration (Coupling/Splitting) and train length.

Note: The detection of Coupling/Splitting events shall be implemented with SIL4. (Subset-034 [1] 2.5.3.2.2 Note: If the train integrity information fails it can be mitigated by detecting a change of the train length.)

7.1.1 Start of Mission – Power-On by Driver

Fun. Req 7. The train devices shall be powered-on by the Driver.

Fun. Req 8. When powered-on, the OTI system shall go into the status of INAUGURATION.

Fun. Req 9. When powered-on, the default OTI state shall be SLAVE unit.

Fun. Req 10. Train Length Determination function and Train Integrity Monitoring function shall be activated when the train is powered-on by the Driver.

7.1.2 Start of Mission – OTI Initialization

Fun. Req 11. Train Length Determination function and Train Integrity Monitoring function shall be started in case of cab activation.

Fun. Req 12. Train Length Determination function and Train Integrity Monitoring function shall be reset in case of cab deactivation or cab changing (and, but only if it's necessary , in case of Driver intervention).

Fun. Req 13. OTI shall identify the head and tail unit or coupler of the train (uncoupled end of the front and rear vehicle of a train composition).

Identification of the first consist at the very front end (Head-Unit):

Fun. Req 14. OTI shall be able to identify the leading consist of the train at the very front end, as the Head-Unit.

Fun. Req 15. OTI shall be able to identify the (uncoupled) head coupler at the leading consist of the train at the very front end, as the Head-Coupler.

Fun. Req 16. OTI shall monitor the HEAD status of the Head Unit and head coupler status.

Identification of the last consist at the very rear end (Tail-Unit):

Fun. Req 17. OTI shall be able to identify the last consist at the very rear end of the train as Tail-Unit.

Note: If only one consist is present, then no Tail-Unit exists.

Fun. Req 18. OTI shall be able to identify the (uncoupled) tail coupler at the last consist of the train at the very rear end, as the Tail-Coupler.

Note: If only one consist is present, then the Tail-Coupler is the rear coupler depending on cab location and driving direction.

Fun. Req 19. OTI shall monitor the TAIL status of the Tail Unit and tail coupler status.

Identification of intermediate consists (Trunk-Unit):

Fun. Req 20. OTI shall be able to identify all remaining consists in the train as Trunks units (NON-TAIL)

Note: If only one Head-Unit and one Tail-Unit are present, then no Trunks exists.

Fun. Req 21. OTI shall monitor the TRUNK status of the Trunk Units and their coupler status.

Master and Slave assignment

Fun. Req 22. After receiving active cab status from ETCS, the corresponding OTI Unit or OTI composition associated to the cab shall be MASTER unit.

Note: The Master is defined at least by the active cab. Depending on the technical solution, Head status and/or coupler status may be used additionally.

Fun. Req 23. OTI Master, after going into MASTER, shall determine all OTI slaves units in the train.

Fun. Req 24. OTI Master, after going into MASTER, shall determine the OTI slaves TAIL status for all OTI slaves units in the train.

Fun. Req 25. Disabling of the cab shall trigger the MASTER unit state to switch to SLAVE unit state.

Fun. Req 26. In each OTI system, composed of OTI Unit or OTI Compositions, only a single OTI unit in MASTER state shall exist.

Fun. Req 27. Due to any change of train composition, a reset of the train length shall be triggered and possibly intiate a SoM procedure by the driver or TCMS, triggering a re-evaluation of train integrity and train length.

Fun. Req 28. Due to the change of the train length as part of train data, a reset of the train length shall be triggered and possibly intiate a SoM procedure by the driver or TCMS, triggering a re-evaluation of train integrity and train length.

7.2 TRAIN LENGTH REQUIREMENTS

7.2.1 Start of Mission – OTI-L Operations

Fun. Req 29. The Train Length (nominal) shall be calculated as the overall distance along the rail from the real head train front and the real tail train end including the couplers.

Fun. Req 30. The Train Length value shall be sent to ETCS-OBU as input provided from external source.

Note: As a proposal for future scenarios, to the Train Length sent to ETCS-OBU, an additional information about the SIL level of the external information may be added to allow conclusion about the quality of data.

Note: The Train Length provided by external source shall be at least SIL2. The Train Length should be provided by external source with SIL4, if possible. If the Train Length is not provided by external source with at least SIL4, the ETCS OBU shall be able to validate the train length value or using additional information to mitigate a wrong train length from external source.

Note: Confirmed train length sent in position report by the ETCS OBU shall be SIL4. This requires a SIL4 train length information to be used for the calculation of the confirmed train length. However this SIL4 train length does not translate into a mandatory SIL4 train length requirement for the OTI; if OTI-L provides the train length already with SIL4 it is sufficient, if OTI-L provides the train length with less than SIL4, then a validation or additional source of information of train length has to be done by ETCS OBU, so that the ETCS OBU could determine a SIL4 train length value using the independent source.

Fun. Req 31. The Train Length shall be calculated internally by OTI-L when it is an information necessary to evaluate Train Integrity (e.g. for wireless communication network or as mitigation and validation of the train integrity or to detect Coupling/Splitting events.)

Fun. Req 32. In case of voluntary change of composition (Coupling/Splitting events), the necessary information (new composition) shall be detected and provided to OTI-L for the new determination of the Train Length.

7.3 TRAIN INTEGRITY REQUIREMENTS

7.3.1 Start of Mission – OTI-I Operations

Fun. Req 33. The train integrity monitoring function operation shall be triggered by the determination and confirmation of train length and train composition.

Fun. Req 34. A confirmation of train integrity (train integrity status confirmed) shall only be possible to provided after the determination and confirmation of train length, otherwise, train integrity status is unknown.

Fun. Req 35. All interactions between train driver/TMS and OTI-L/OTI-I of the train shall be integrated into the ETCS driver interface (DMI), if any interaction is required.

Fun. Req 36. Any necessary interactions of train driver with OTI-I shall be kept to a minimum.

Fun. Req 37. Initialization of OTI-I and determination of train integrity status shall not require to be started additionally by the driver.

Fun. Req 38. The presence and use of the OTI system shall not influence the operation, e.g. Coupling or Splitting, except for the resulting modification of the train data in the SoM procedure.

7.3.2 Mission – OTI-I Train Integrity Status Monitoring

Confirmation and continuous monitoring of train integrity:

Fun. Req 39. The OTI-I continuously confirms and monitors the completeness (integrity) of a train consisting of several (two or more) consists (vehicles or wagons) that could separate unintendedly.

Monitoring the integrity status of the train between consists or OTI Compositions:

Fun. Req 40. OTI-I shall monitor the integrity status of the entire train incl. all OTI Unit and/or OTI Compositions.

Fun. Req 41. OTI-I shall continuously verify the train integrity after Start of Mission incl. determination and validation of the train composition and train length and during train operation and provide the integrity status of the train to the ETCS OBU via the train interface (Subset-034 [1])

Monitoring the integrity status of the train within a vehicle unit (consist):

Fun. Req 42. OTI-I shall continuously determine and monitor the integrity of each vehicle unit of several (two or more) subunits (vehicles or wagons) that could separate unintendedly.

Note: This sub-function is not required if the failure of the mechanical Joining system between two wagons is considered very unlikely. (e.g. Jacobs bogies)

Fun. Req 43. If the train integrity cannot be confirmed by OTI-I (e.g., train integrity information is not available, or train integrity is lost), OTI-I shall not send a confirmed train integrity status (Q_INTEGRITY == 1). Generate output of the train integrity status (Q_INTEGRITY) to the ETCS-OBU:

a) OTI-I shall provide an output to the ETCS OBU with the information, that a) the integrity of the train is confirmed, or

b) the integrity of the train has been lost if there is any change in the train composition, or

c) the integrity of the train is unknown if the integrity of the train cannot be determined.

Fun. Req 44. If there is a change in the train configuration, intended or unintended, the OTI-I shall send the integrity LOST status (Subset-034 [1] 2.5.3.2.1" In case of detected train split intentional or unintentional) or a train joining, the vehicle shall provide the information "Train integrity lost"".)

Fun. Req 45. OTI-I shall reevaluate TAIL status (e.g. coupler status) at standstill to determine Joining or Splitting events.

Note: Train integrity status determination may be mitigated by train composition and/or train length determination, to achieve sufficient safety level for the detection of an intended change of train composition. (Subset-034 [1] 2.5.3.2.2 Note: If the train integrity information fails it can be mitigated by detecting a change of the train length.)

Note: If there is an intended change in the train configuration (Coupling or Splitting), the OTI-I triggers the OTI-L to determines the resulting train length,

7.3.3 OTI DAC interface

IF-Req 4. The OTI DAC interface shall implement an interface of the DAC to transfer the data for train integrity and train length.

IF-Req 5. A standard interface between the OTI Master and OTI Slaves, provided by the OTI Unit or composition shall be implemented according to a FFFIS specification.

IF-Req 6. The OTI DAC interface shall implement standardized messages incl. bit and fields.

IF-Req 7. The OTI DAC interface shall implement standardized sequences, use cases and behavior.

IF-Req 8. The OTI DAC interface shall implement standardized input and output (triggers and variables)

IF-Req 9. The OTI DAC interface shall implement standardized functional behavior including states and transitions of being the master, slave, assignment, pairing, unpairing, head and tail etc.

IF-Req 10. The OTI DAC interface shall implement a standardized interface to collect the data of the adjacent OTI Composition to enable the OTI Composition Master to provide the arrangement and the orientation of each vehicle or consist in the whole train.

7.4 OTI Composition Requirements

7.4.1 OTI composition interface

IF-Req 11. The interface OTI–I to OTI–I for OTI Compositions shall be implemented according to a standardized specification, providing a standardized interface (at least FIS), information and functional behaviour.

IF-Req 12. The interface OTI–L to OTI–L for OTI Compositions shall be implemented according to a standardized specification, providing a standardized interface (at least FIS), information and functional behaviour.

IF-Req 13. A OTI Composition shall provide Train Integrity status with the same SIL as a generic OTI Master.

IF-Req 14. A OTI Composition shall provide Train Length value with the same SIL as a generic OTI Master.

IF-Req 15. A OTI composition Master shall receive train integrity status from other OTI Compositions.

IF-Req 16. A OTI composition slave shall provide train integrity status to other OTI Compositions.

IF-Req 17. A OTI composition Master shall receive train length values from other OTI Compositions.

IF-Req 18. A OTI composition slave shall provide its train length value to other OTI Compositions.

IF-Req 19. A OTI composition Master shall receive TAIL status from other OTI Compositions.

IF-Req 20. A OTI composition Slave shall provide TAIL status to other OTI Compositions.

IF-Req 21. OTI-I system shall monitor the HEAD status (e.g. head coupler status) of the OTI composition assigned as HEAD

IF-Req 22. OTI-I system shall monitor the TAIL status (e.g. TAIL coupler status) of the OTI composition assigned as TAIL, if existing.

IF-Req 23. OTI-C shall provide Train Integrity information with the same SIL as a generic OTI Master

IF-Req 24. OTI-C shall provide Train Length value with the same SIL as a generic OTI Master

IF-Req 25. OTI-C shall provide its own state which will be the result of the state of the connected OTI-Cs.

Fun. Req 46. The DAC shall provide the Train Length in every configuration (included Cab Anywhere)

Fun. Req 47. If the safety level of the provided Train Length is not SIL4, OTI must adopt a procedure to ensure requested level

IF-Req 26. Depending on the required safety level, OTI-Composition can or not adopt a check on Train Length using trackside system to validate it

Fun. Req 48. In case of combination between OTI-Compositions, an OTI-Composition shall be able to provide the length of his associated units to the other OTI-Compositions

Fun. Req 49. The OTI-Composition shall be able to determine the complete Train Length and send it to ETCS-OBU

CONCLUSIONS

This document is the result of the activities carried out in WP19 of the R2DATO project. Even though the twelve-month duration was challenging, the result obtained is in line with what was expected and reported in the GA. The project started with an initial phase of alignment between the partners who came from different experiences and with backgrounds in non-identical fields.

This first phase allowed the different knowledge to be shared and transferred in a transversal way. In this first phase, the documents that came from previous projects were also studied, in particular those of X2Rail-2 and X2Rail-4.

WP19 has also started to interact with FP5 where the DAC solution is developed which is usable for the purposes of WP19. The goal of WP19 is to consolidate the specifications for Train Integrity and for Train Length determination functions.

Some misunderstandings arose due to the different approaches of the partners involved but they have been overcome. the first step achieved was to use the recently issued TSIs as a starting point for definitions of the operations to be undertaken.

The interaction with the FP5 partners allowed us to take charge of a first version of the DAC solution. The point that characterized the work done in task 19.1 and in subtasks 19.1.1 and 19.1.2 was to try to make the management of Train Integrity and the determination of Train Length independent of the technology used to implement the function.

This has been challenging and not completely finished because a fully interoperable interface has not been defined, an FFFIS interface has not yet been defined.

However, the efforts made have allowed us to define applicable concepts that preserve the good work done in previous projects but allow for greater flexibility.

Even the requirements that have been consolidated, the activity is not finished, are a valid point for the continuation of the activities that will be carried out in the WP20 foreseen in the GA.

The results obtained in WP19 and reported here can be summarized in:

- Alignment with TSI Baseline 4 and consolidation of specifications
- Clarification of the operational aspects related to Train Integrity and Train Length
- Insertion of the use of the DAC at a functional level
- Introduction of the concept of OTI Unit and OTI Composition

These will be the starting points of the WP20 activities of the R2DATO project.

Moreover, the WP20 shall be used to define the details of the FFFIS interfaces and the different options to connect the cars to hand over the data's within a composition. As shown in this document, the Product Class X can have very different and individual solutions to provide the train integrity and train length data. For the OTI Unit concept, there shall be three options considered:

- OTI Unit are connected with individual supplier solutions
- OTI Unit are connected with a standard cable and connector
- OTI Unit are connected with the DAC

Each OTI Unit equipped with a DAC is already defined as an OTI Composition to provide the full functionality. The OTI Composition need to collect the data of the adjacent OTI Composition connected to A-end and B-end and send this information to the OTI Composition Master in a defined package. The OTI Composition Master is than able to calculate the arrangement and the orientation of each OTI Composition in the whole consist. Furter details to be defined are:

- Implement standardized sequences, use cases and behaviour
- Implement Input and output (triggers and variables)
- Standardized states and transitions of being the master, slave, assignment, pairing, unpairing, head and tail etc.

In conclusion, the expected objectives were achieved, and a concrete contribution was made to the simplification of operations. This is also a step towards integrating this function into a fully automated environment.

REFERENCES

[1] X2Rail-2 - Deliverable D4.1 Train Integrity Concept and Functional Requirements Specifications v. 2.3

[2] X2Rail-2 - Deliverable D4.2 Functional architecture & Interfaces specifications & Candidate technologies selection v. 3.0

[3] X2Rail-2 - Deliverable D4.3 Test scenarios & test cases specifications v. 2.0

[4] X2Rail-4 - D7.3 Standardisation Proposal v. 1.2

[5] X2Rail-4 - Deliverable D7.2 OTI Technology Migration v. 2.0

[6] System Pillar Task 4 DAC / FDFTO WP3.1 FDFTO-ERTMS/ETCS 26/05/2023 revision Draft v. 1.0

[7] ERTMS/ETCS Train Interface FFFIS SUBSET-119 ISSUE: 4.0.0 DATE: 2023-07-05

[8] EN50159 Safety related communication in transmission systems

[9] IEC61375-2-3 TCN – Train Communication Network – Communication Profile 2015

[10] ERTMS/ETCS Train Interface FIS SUBSET-034 VERSION: 4.0.0 DATE: 05/07/2023

[11] ERTMS/ETCS System Requirements Specification SUBSET-026 VERSION: 4.0.0 DATE: 05/07/2023

[12] ERTMS/ETCS Interoperable performance requirements SUBSET-041 VERSION: 4.0.0 DATE: 05/07/2023

[13] ERTMS/ETCS Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2 FIS SUBSET-091 VERSION: 4.0.0 DATE: 05/07/2023

[14] ERTMS/ETCS FFFIS TI – Safety related Requirements SUBSET-120 VERSION: 4.0.0 DATE: 05/07/2023

APPENDIX 1. REQUIREMENTS

This chapter reports the list of the requirements present in this document.

Ther are four tables one for every main requirement families:

1 Operational Requirements

2 Functional Requirements

3 Non-Functional Requirements (including safety and performance requirements)

4 Interface Requirements for DAC and OTI Composition interface

These tables will be use also for traceability reasons in the subsequent phases of the project.

OPERATIONAL REQUIREMENTS

ID	Operational Requirements
Op Req1	Both train integrity (OTI-I) and train length (OTI-L) functions shall be automatically reset / re-evaluated when the cab is activated. Example: during train joining or splitting procedure, a reset of the cab shall automatically trigger the reset of both train integrity and train length.
Op Req2	The train integrity monitoring function shall be triggered by the confirmation of train length. Disabling of the cab shall trigger the deactivation of the train integrity monitoring function.
Op Req3	All interactions between train Driver/TMS and OTI-L/OTI-I of the train shall be integrated into the ETCS driver interface (DMI) or in the TCMS interface.
Op Req4	Due to the change of train composition a reset of the train length shall be possible by the driver/TMS, triggering a re-evaluation of train integrity and train length.
Op Req5	Necessary interactions of train driver with OTI-L shall be kept to a minimum.
Op Req6	Initialization of OTI-I and OTI-L shall not to be started additionally by the driver.
Op Req7	For OTI-I and OTI-L systems based on wireless solutions, it shall be granted a reliable communication between their constituents.
Op Req8	The solutions associated with the OTI-I and OTI-L functions must be as interoperable as possible, without depending on the technology adopted.
Op Req9	Train Integrity information must be transmitted from OTI-I to ETCS OBU.
Op Req10	In case the Train Integrity Value (CONFIRMED; CONFIRMED DR, LOST; UNKNOWN) is to be made visible to the train driver, this shall be implemented on the ETCS DMI.
Op Req11	Any change in Train Integrity Value shall be visible to the train driver, for example by blinking on the DMI where OTI information is displayed. Examples:
Op Req12	A loss of train integrity (Value change CONFIRMED --> LOST) shall lead to a warning sound or other measure in order to warn the train driver.
Op Req13	Train Length information must be transmitted from OTI-L to ETCS OBU.

ID	Operational Requirements
Op Req14	Train Length (Validated) Value shall be visible to the train driver at any time during operation.
Op Req15	In case the train length determination on the necessary SIL level is provided by technical equipment only, no further action from the train driver shall be required.
Op Req16	In case an interaction with the train driver is necessary for entering or confirmation of train length, this shall be possible using the DMI only.
Op Req17	In case train driver input is used for train length validation, only integer values shall be entered and taken into consideration.
Op Req18	Train length unit shall be metric (SI) metres.
Op Req19	Any interaction regarding train length (e.g. entering train length manually by the driver) shall be limited to the SoM process when the train is standstill.
Op Req20	In case train length data is to be entered by the train driver and the entered value differs from the automatically calculated train length value, this information shall be indicated to the driver.

Table 13: Operational Requirements

Functional Requirements

ID	Functional Requirements
Fun. Req 1	At least one OTI Unit shall be associated with each consist.
Fun. Req 2	Each OTI Unit shall, as a minimum, provide the integrity status and length of the associated consist to the OTI Master.
Fun. Req 3	One or multiple OTI Unit shall be able to be combined to form an OTI Composition for a consist or train.
Fun. Req 4	An OTI Composition shall, as a minimum, provide the integrity status and length of its associated OTI Unit to other OTI Compositions.
Fun. Req 5	The interface between the OTI system to the ETCS OBU shall be realized according to the TSI CCS 2023 (version 4.0) and especially with regard to the train interface specified Subset-034 [1] Train Interface FIS and Subset-119 [1] Train Interface FFFIS)
Fun. Req 6	The OTI system shall detect intended changes to the train configuration (Coupling/Splitting) and train length.
Fun. Req 7	The train devices shall be powered-on by the Driver.
Fun. Req 8	When powered-on, the OTI system shall go into the status of INAUGURATION.
Fun. Req 9	When powered-on, the default OTI state shall be SLAVE unit.
Fun. Req 10	Train Length Determination function and Train Integrity Monitoring function shall be activated when the train is powered-on by the Driver.

ID	Functional Requirements
Fun. Req 11	Train Length Determination function and Train Integrity Monitoring function shall be started in case of cab activation.
Fun. Req 12	Train Length Determination function and Train Integrity Monitoring function shall be reset in case of cab deactivation or cab changing (and, but only if it's necessary , in case of Driver intervention).
Fun. Req 13	OTI shall identify the head and tail unit or coupler of the train (uncoupled end of the front and rear vehicle of a train composition).
Fun. Req 14	OTI shall be able to identify the leading consist of the train at the very front end, as the Head-Unit.
Fun. Req 15	OTI shall be able to identify the (uncoupled) head coupler at the leading consist of the train at the very front end, as the Head-Coupler.
Fun. Req 16	OTI shall monitor the HEAD status of the Head Unit and head coupler status.
Fun. Req 17	OTI shall be able to identify the last consist at the very rear end of the train as Tail-Unit.
Fun. Req 18	OTI shall be able to identify the (uncoupled) tail coupler at the last consist of the train at the very rear end, as the Tail-Coupler.
Fun. Req 19	OTI shall monitor the TAIL status of the Tail Unit and tail coupler status.
Fun. Req 20	OTI shall be able to identify all remaining consists in the train as Trunks units (NON-TAIL)
Fun. Req 21	OTI shall monitor the TRUNK status of the Trunk Units and their coupler status.
Fun. Req 22	After receiving active cab status from ETCS, the corresponding OTI Unit or OTI composition associated to the cab shall be MASTER unit.
Fun. Req 23	OTI Master, after going into MASTER, shall determine all OTI slaves units in the train.
Fun. Req 24	OTI Master, after going into MASTER, shall determine the OTI slaves TAIL status for all OTI slaves units in the train.
Fun. Req 25	Disabling of the cab shall trigger the MASTER unit state to switch to SLAVE unit state.
Fun. Req 26	In each OTI system, composed of OTI Unit or OTI Compositions, only a single OTI unit in MASTER state shall exist.
Fun. Req 27	Due to any change of train composition, a reset of the train length shall be triggered and possibly intiate a SoM procedure by the driver or TCMS, triggering a re-evaluation of train integrity and train length.
Fun. Req 28	Due to the change of the train length as part of train data, a reset of the train length shall be triggered and possibly intiate a SoM procedure by the driver or TCMS, triggering a re-evaluation of train integrity and train length.

ID	Functional Requirements
Fun. Req 29	The Train Length (nominal) shall be calculated as the overall distance along the rail from the real head train front and the real tail train end including the couplers.
Fun. Req 30	The Train Length value shall be sent to ETCS-OBU as input provided from external source.
Fun. Req 31	The Train Length shall be calculated internally by OTI-L when it is an information necessary to evaluate Train Integrity (e.g. for wireless communication network or as mitigation and validation of the train integrity or to detect Coupling/Splitting events.)
Fun. Req 32	In case of voluntary change of composition (Coupling/Splitting events), the necessary information (new composition) shall be detected and provided to OTI-L for the new determination of the Train Length.
Fun. Req 33	The train integrity monitoring function operation shall be triggered by the determination and confirmation of train length and train composition.
Fun. Req 34	A confirmation of train integrity (train integrity status confirmed) shall only be possible to provided after the determination and confirmation of train length, otherwise, train integrity status is unknown.
Fun. Req 35	All interactions between train driver/TMS and OTI-L/OTI-I of the train shall be integrated into the ETCS driver interface (DMI), if any interaction is required.
Fun. Req 36	Any necessary interactions of train driver with OTI-I shall be kept to a minimum.
Fun. Req 37	Initialization of OTI-I and determination of train integrity status shall not require to be started additionally by the driver.
Fun. Req 38	The presence and use of the OTI system shall not influence the operation, e.g. Coupling or Splitting, except for the resulting modification of the train data in the SoM procedure.
Fun. Req 39	The OTI-I continuously confirms and monitors the completeness (integrity) of a train consisting of several (two or more) consists (vehicles or wagons) that could separate unintendedly.
Fun. Req 40	OTI-I shall monitor the integrity status of the entire train incl. all OTI Unit and/or OTI Compositions.
Fun. Req 41	OTI-I shall continuously verify the train integrity after Start of Mission incl. determination and validation of the train composition and train length and during train operation and provide the integrity status of the train to the ETCS OBU via the train interface (Subset-034 [1])
Fun. Req 42	OTI-I shall continuously determine and monitor the integrity of each vehicle unit of several (two or more) subunits (vehicles or wagons) that could separate unintendedly.
Fun. Req 43	If the train integrity cannot be confirmed by OTI-I (e.g., train integrity information is not available, or train integrity is lost), OTI-I shall not send a confirmed train integrity status (Q_INTEGRITY == 1).

ID	Functional Requirements
Fun. Req 44	If there is a change in the train configuration, intended or unintended, the OTI-I shall send the integrity LOST status (Subset-034 [1] 2.5.3.2.1" In case of detected train split intentional or unintentional) or a train joining, the vehicle shall provide the information "Train integrity lost"".)
Fun. Req 45	OTI-I shall reevaluate TAIL status (e.g. coupler status) at standstill to determine Joining or Splitting events.
Fun. Req 46	The DAC shall provide the Train Length in every configuration (included Cab Anywhere)
Fun. Req 47	If the safety level of the provided Train Length is not SIL4, OTI must adopt a procedure to ensure requested level
Fun. Req 48	In case of combination between OTI-Compositions, an OTI-Composition shall be able to provide the length of his associated units to the other OTI-Compositions
Fun. Req 49	The OTI-Composition shall be able to determine the complete Train Length and send it to ETCS-OBU

Table 14: Functional Requirements

NON-FUNCTIONAL REQUIREMENTS

ID	Non-Functional Requirements
Non-Fun. Req 1	All faults of the OTI system shall be detected, within 24 hours at the latest. (Subset-120 [1] FFFIS TI – Safety-related requirements 2.1.6.3 Train Integrity 2.1.6.3.3.5 FDT for the signals = 24 h)
Non-Fun. Req 2	The overall train integrity monitoring function shall achieve at least SIL 2. (Subset-091 [1] 9.6. EXT_SR08)

Table 15: Non-Functional Requirements

INTERFACE REQUIREMENTS FOR DAC AND OTI COMPOSITION

ID	Interface-Requirements for DAC and OTI-C
IF-Req 1	OTI-C must provide Train Integrity information with the same SIL as a generic OTI Master
IF-Req 2	OTI-C must provide Train Length value with the same SIL as a generic OTI Master
IF-Req 3	OTI-C must provide its own state which will be the result of the state of the connected OTI-Cs. All it takes is for just one OTI-C to be faulty and the overall state will be Fault.
IF-Req 4	The OTI DAC interface shall implement an interface of the DAC to transfer the data for train integrity and train length.
IF-Req 5	A standard interface between the OTI Master and OTI Slaves, provided by the OTI Unit or composition shall be implemented according to a FFFIS specification.
IF-Req 6	The OTI DAC interface shall implement standardized messages incl. bit and fields.

ID	Interface-Requirements for DAC and OTI-C
IF-Req 7	The OTI DAC interface shall implement standardized sequences, use cases and behavior.
IF-Req 8	The OTI DAC interface shall implement standardized input and output (triggers and variables)
IF-Req 9	The OTI DAC interface shall implement standardized functional behavior including states and transitions of being the master, slave, assignment, pairing, unpairing, head and tail etc.
IF-Req 10	The OTI DAC interface shall implement a standardized interface to collect the data of the adjacent OTI Composition to enable the OTI Composition Master to provide the arrangement and the orientation of each vehicle or consist in the whole train.
IF-Req 11	The interface OTI–I to OTI–I for OTI Compositions shall be implemented according to a standardized specification, providing a standardized interface (at least FIS), information and functional behaviour.
IF-Req 12	The interface OTI–L to OTI–L for OTI Compositions shall be implemented according to a standardized specification, providing a standardized interface (at least FIS), information and functional behaviour.
IF-Req 13	A OTI Composition shall provide Train Integrity status with the same SIL as a generic OTI Master.
IF-Req 14	A OTI Composition shall provide Train Length value with the same SIL as a generic OTI Master.
IF-Req 15	A OTI composition Master shall receive train integrity status from other OTI Compositions.
IF-Req 16	A OTI composition slave shall provide train integrity status to other OTI Compositions.
IF-Req 17	A OTI composition Master shall receive train length values from other OTI Compositions.
IF-Req 18	A OTI composition slave shall provide its train length value to other OTI Compositions.
IF-Req 19	A OTI composition Master shall receive TAIL status from other OTI Compositions.
IF-Req 20	A OTI composition Slave shall provide TAIL status to other OTI Compositions.
IF-Req 21	OTI-I system shall monitor the HEAD status (e.g. head coupler status) of the OTI composition assigned as HEAD
IF-Req 22	OTI-I system shall monitor the TAIL status (e.g. TAIL coupler status) of the OTI composition assigned as TAIL, if existing.
IF-Req 23	OTI-C shall provide Train Integrity information with the same SIL as a generic OTI Master
IF-Req 24	OTI-C shall provide Train Length value with the same SIL as a generic OTI Master

ID	Interface-Requirements for DAC and OTI-C
IF-Req 25	OTI-C shall provide its own state which will be the result of the state of the connected OTI-Cs.
IF-Req 26	Depending on the required safety level, OTI-Composition can or not adopt a check on Train Length using trackside system to validate it

Table 16: Interface Requirements for DAC and OTI-C

APPENDIX 2. SPECIAL CASE

This Chapter reports the Train Length Determination for wireless, it is a special case,

The OTI-Composition with wireless communication channel, is strictly related to the Class 2 of X2Rail.

In Class 2 the hazard analysis highlighted the safety problem in determining the train length (according with CR940).

This case is different from Class 1 (wired connection) and Class 3 (wireless connection, but integrity defined by verifying the separation between adjacent wagons) and OTI-Composition with DAC, able to determine automatically the train composition and the train length.

In case of Class 2 can be considered the requested SIL level for Train Length to send to ETCS if the scope is to allow the train to enter ERTMS L3.

If the requested level is SIL2, the Train Length to be send to ETCS, can be acquire from an external source (external respect to ETCS) that can be the TMS. This operation can be performed when the train is in standstill, according with the following diagram in Figure 28.

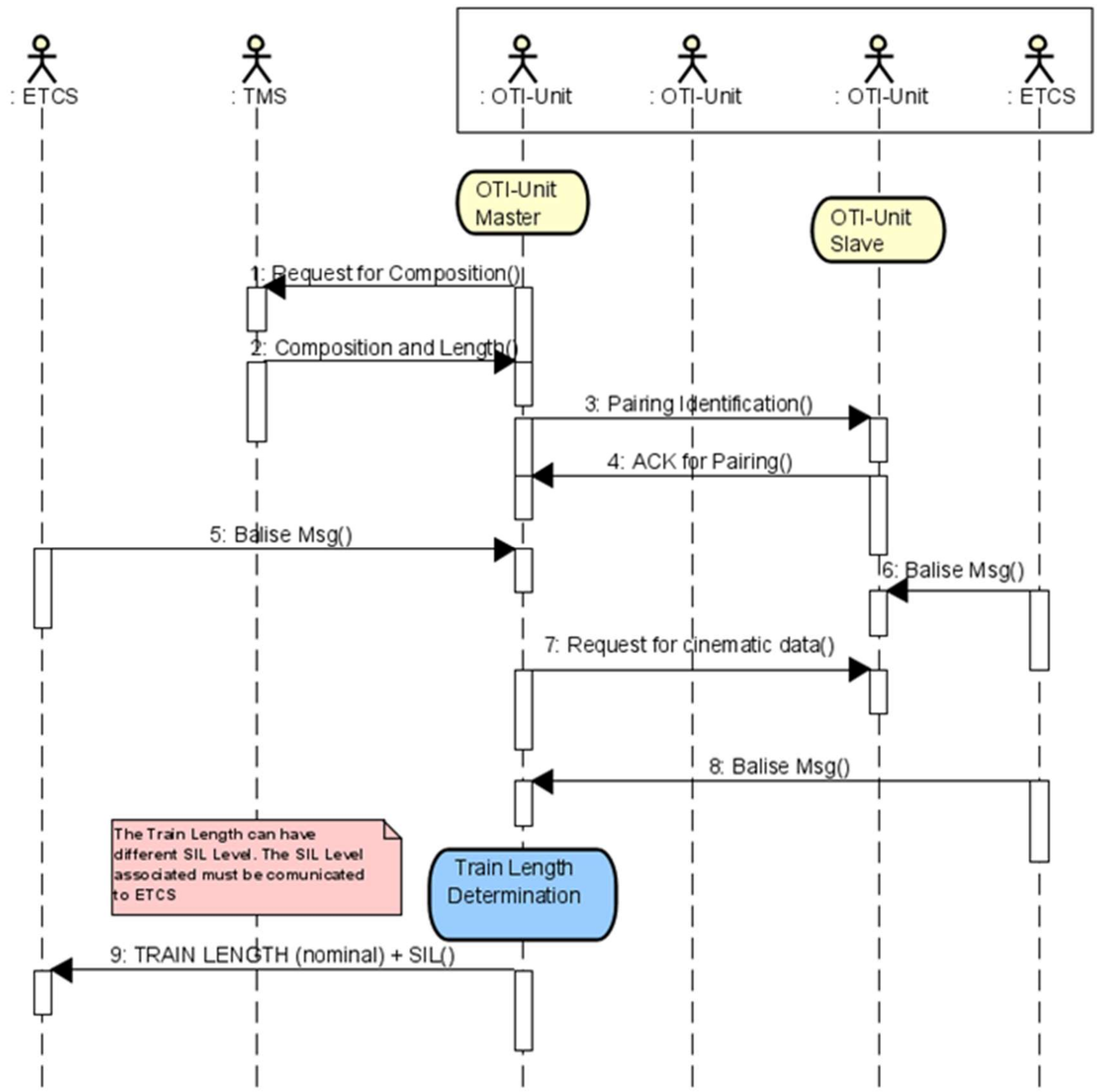

Figure 28

But if the requested level is SIL4, the Train Length shall be validated using trackside. This operation can only be done with the train moving as the Balises must be "read". The diagram in the Figure 28 also contains this possibility.

The Class 2 composition that can be used to enter ERTMS L3 contains an ETCS at the head of the train and an ETCS at the tail.