Rail to Digital automated up to autonomous train operation

D6.6 – Documentation of Use cases, requirements & Specification autonomous operations for tramways

Due date of deliverable: 31/12/2024

Actual submission date: 21/11/2024

Leader/Responsible of this Deliverable: Igor Lopez (CAF)

Reviewed: Y

Document status		
Revision	Date	Description
01	01/02/2024	First issue
02	23/05/2024	Adjustment of structure to adapt it to EN50126
03	24/07/2024	First complete version of the deliverable
04	16/10/2024	Final draft ready for TMT review
05	21/11/2024	After TMT review

Project funded from the European Union's Horizon Europe research and innovation programme		
Dissemination Level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	

Start date: 01/12/2022 Duration: 42 months

ACKNOWLEDGEMENTS

This project has received funding from the Europe's Rail Joint Undertaking (ERJU) under the Grant Agreement no. 101102001. The JU receives support from the European Union's Horizon Europe research and innovation programme and the Europe's Rail JU members other than the Union.

REPORT CONTRIBUTORS

Name	Company	Details of Contribution
Igor Lopez	CAF	Led the development and execution of the T6.6 and corresponding the deliverable. From the Concept and operational use cases received from T5.6 defined the ATO architecture following the EN50126 process up to system definition.
Dusan Patrick Klago	Sporveien	Provided the expertise and experience of Sporveien Trikken urban operations to define the actors involved in the operational use cases and which ones could be substituted/minimized by automatization. Review of the whole document.
Daria Kuzmina	UITP	Provided the expertise and experience of from different urban operators to define the actors involved in the operational use cases and which ones could be substituted/minimized by automatization. Organized a meeting with UITP members to provide value feedback from different operators. Review of the whole document.

EXECUTIVE SUMMARY

The development and execution of T6.6 were driven by the need to advance urban transportation systems through automatization. Leveraging the concept and operational use cases provided by T5.6, the ATO (Automatic Train Operation) architecture was defined following the EN50126 process up to the system definition stage. This initiative is crucial for enhancing the efficiency and effectiveness of urban transport operations, thereby benefiting tramway operators and contributing to the broader goals of sustainability and innovation in public transportation.

The primary objective of this deliverable was to establish a robust ATO architecture for urban transport systems. Building on existing knowledge and methodologies, the team incorporated expertise from various urban operators, including Sporveien and other operators associated to UITP. The approach involved defining the actors in the operational use cases and determining which roles could be automated. Collaborative efforts, including meetings organized by UITP, ensured a comprehensive and balanced view of the requirements and potential solutions.

The deliverable successfully outlined the ATO architecture, highlighting the potential for significant improvements in urban transport through automatization. Key findings include the identification of roles that can be minimized or substituted with automated systems, leading to enhanced operational efficiency. As justified in this deliverable, for Remote Driving in depots, 77 of the 86 logical functions can be automated or controlled by a Remote Operator, whereas for autonomous manoeuvres, this figure increases to 78 out of 87.

The work presented in this deliverable is considered comprehensive, though further research and innovation (R&I) may be needed for full deployment and validation. Future steps include addressing the low-level system specification, development and validation which will be made within the R2DATO Task 10.2.

ABBREVIATIONS AND ACRONYMS

ADAS	Advanced driving Assistance System
ASDO	Automatic Selective Door Operation
ATO	Automatic Train Operation
ATO_OB	Automatic Train Operation On-Board module
ATO_TS	Automatic Train Operation Trackside module
ATP	Automatic Train Protection
BCU	Brake Control Unit
CCAM	Cooperative, Connected and Automated Mobility
CCTV	Closed Circuit Television
C-ITS	Cooperative Intelligent Transport Systems
DAS	Driver Advisory System
DMI	Driver-Machine Interface
ECM	Entity in Charge of Maintenance
FP2	Framework Programme 2
GoA	Grade of Automation
GoA2+	Grade of Automation 2 with additional functionalities
GNSS	Global Navigation Satellite System
HMI	Human-Machine Interface
HVAC	Heating, ventilation, and air conditioning
IM	Infrastructure Manager
IPM	Incident Protection Manager
IPM_OB	Incident Protection Manager On-Board Module
JP	Journey Profile
LOZ	Safe Location System
MAR	Mobile Access Router
MP	Mission Profile
OBU_V2X	On-Board Module for V2X communications
OCC	Operations Control Centre
ORDM	On-Board Remote Driving Module

PER	Perception System
PER_OB	Perception On-Board System
PHA	Preliminary Hazard Analysis
PIS	Passenger Information System
PMR	Professional Mobile Radio
R2DATO	Rail to Digital automated up to autonomous train operation
RFID	Radio Frequency Identification
ROC	Remote Driving & Telecommand Operation Centre
SRAC	Safety Related Application Conditions
SRR	System Requirement Review
TCMS	Train Control and Monitoring System
TCU	Train Control Unit
TETRA	Terrestrial Trunked Radio
TLM	Telemetry service
TIS	Train Information System
TMS	Automatic Traffic Management System
TSR	Temporal Speed Restriction
UTC	Coordinated Universal Time
VSS	Video Streaming System
V2X	Vehicle-to-Everything
WP	Work Package

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1. INTRODUCTION

The present document “Documentation of Use cases, requirements & Specification autonomous operations for tramways”, is the deliverable D6.6 of the task T6.6 or the Work Package 6 of R2DATO project.

The task 6.6 aims to tackle the increasing interest and demands of tramway operators on the automatization of tram functions and operations. Within this task the ATO technology solutions for trams have been defined to address two main applications; autonomous operations in depot and autonomous service operation.

These two applications have different level of automatization, being the aim of the task to fully automatize the operations in depot but defining a GoA2+ as a target for service operations.

The IEC 62290-1 defines the various levels of automation and the minimum mandatory functions required to achieve these levels. The standard defines five levels of automation:

- GoA 0 – Line of Sight Operations
- GoA 1 – Non-Automated Train Operation
- GoA 2 – Semi Automated Train Operation
- GoA 3 – Driverless Train Operation (DTO)
- GoA 4 – Unattended Train Operation (UTO)

The ambition of this document is to define an architecture capable to achieve GoA4 in depot operations and a GoA2 plus additional functions from GoA3 which could make the tram operation more efficient and safe.

The specification of ATO architecture has been made following the V-cycle described in the EN 50126 depicted in Figure 1.

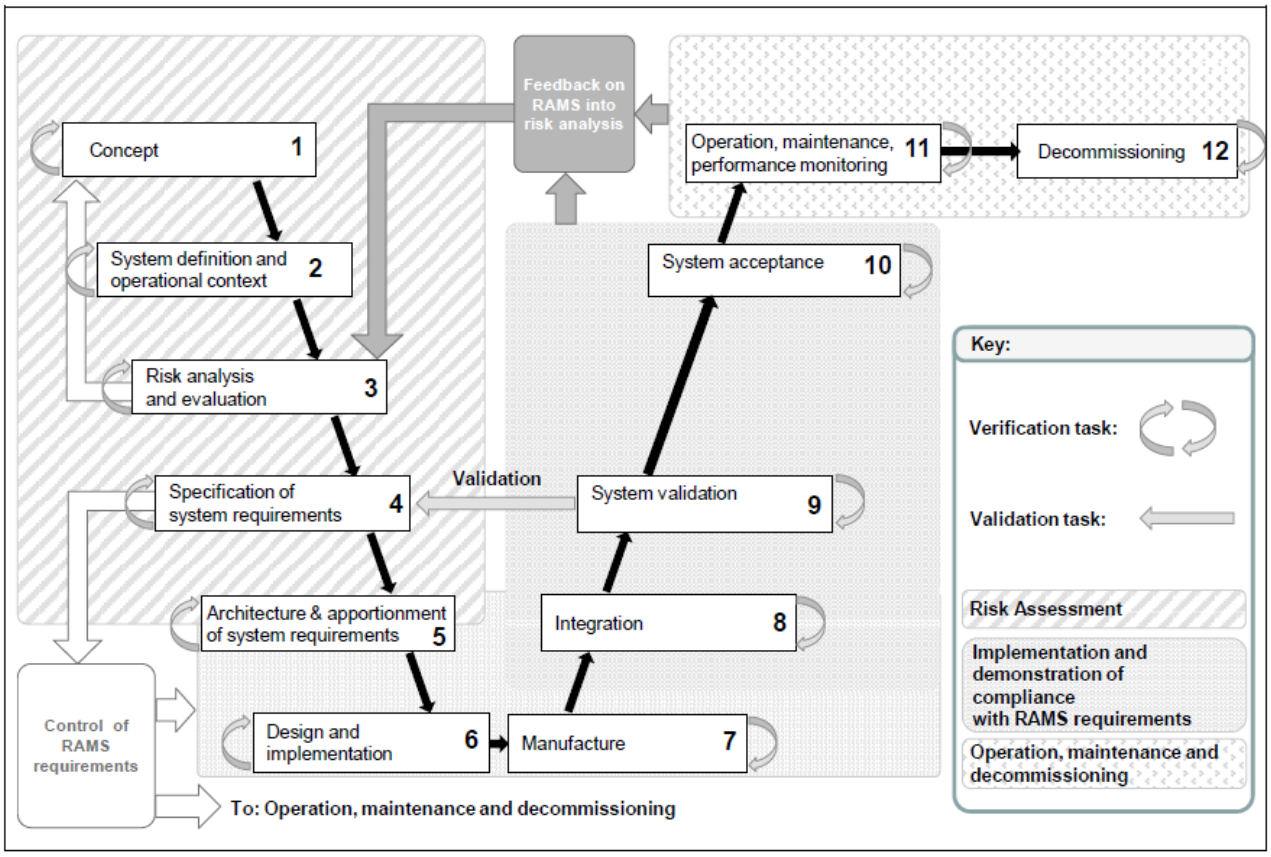


Figure 1: The V-cycle representation (source EN50126-1:2017)

The **Concept** for the ATO operations in tramway to be addressed within R2DATO is described in section 2.

The **System definition and operational context** is based on this concept and taking the operational use cases defined in D5.6 “Documentation of urban user cases and operational rules for automation process” [2].

The **Risk analysis and evaluation** is introduced in section 0 where a Preliminary hazard Analysis has been made, resulting in the definition of a set of system requirements and safety related application conditions.

For the **Specification of system requirements** section 5 takes as a reference the logical functions defined in X2Rail-4 D3.2 [1], discarding one not applicable to tramway systems, translating to tramway use cases those which are applicable and clustering them in nine groups. From the operational functions coming from T5.6 [2], sequence diagrams to detect the actors of the ATO architecture involved in each operational use case and the logical functions needed to perform them are made in section 6.

Section 7 describes the **Architecture and apportionment of logical functions** for each architecture module.

From the specification made in this document, it is expected that R2DATO Task 10.2 carries out the deployment and validation of the ATO functionalities for tramway systems.

Section 0 introduced a comparison of the function assignment to different actors between legacy operative and automated operatives which evidences the saving in time and personnel in involved.

Lastly, section 9 closes the document with the conclusions obtained from the work made in Task 6.6.

2. CONCEPT

Tramway operational environment differs from mainline and therefore this segment has specific use cases and user requirements. Moreover, there is no common view in Europe, as each local operator has its needs in terms of use cases and operational rules. Due to this fact, it is convenient to stay the objectives of Task 6.6 of R2DATO related to ATO operations for tramways. Currently, operators all around the world have started requesting functionalities in new tram models to perform functions remotely and autonomously in depots. The reasons behind are twofold: firstly, to optimize maintenance and other depot operations in terms of cost and time; and second, to overcome the lack of drivers by reducing the number of them needed for movements in depot and using them in operation. Additionally, tramways is an special guided transport comparing to other railway systems, since the road and platforms are shared with other transportation means which behave unpredictable for the traffic manager and the tram driver. This fact is reflected in more hazardous situations which many times implies collisions and accidents resulting in injuries and damages.

The objective of R2DATO Task 6.6 regarding ATO operations in tramways can be divided into functions in controlled areas (e.g. depot) and functions in commercial operation.

The main objectives for controlled areas are:

1. Remote Driving and Telecommand functions without passengers
2. Unattended Autonomous Movements without passengers

The main objective for non-controlled areas, such as commercial operations, is:

1. Advanced Driver Advisory System with functionalities equivalent to a GoA2+

Related to Remote Control and Driving operations in depot, these are the main use cases to be covered within this task:

- ✓ Remote selection and start-up of units.
- ✓ Remote selection and shutdown of units.
- ✓ Static driver telecommands.
- ✓ Remote checks for operation.
- ✓ Real time and low latency video streaming of indoor and outdoor cameras.
- ✓ Change of operational modes: Low consumption, shunting, cleaning mode, etc.
- ✓ Remote cabin selection (at standstill).
- ✓ Remote driving from remote control centre at low speed.
- ✓ Stopping of vehicle in front of obstacle.
- ✓ Low speed precision parking.

Related to Unattended Autonomous Movements in depot, these are the main use cases to be covered within this task:

- ✓ Programmable sequences for remote startup and shutdown of units.
- ✓ Execution of programs for automatic start for service entry.

- ✓ Programming of fleet sequences to be executed.
- ✓ Stopping the vehicle in front of an obstacle.
- ✓ Permanent communication with remote control centre. Real-time diagnosis and reporting of fleet status.
- ✓ Traction and braking commands based on energy saving curves.
- ✓ Derailment detection.
- ✓ Detection and classification of objects on the track: vehicles, branches, stones, etc.

Lastly, for the Advanced Driver Advisory System equivalent to GoA2+ in commercial operations, these are the use cases to be covered within this task:

- ✓ Automated driving based on schedule compliance curves and energy consumption optimization.
- ✓ Identification, classification and tracking of obstacles for safe decision making.
- ✓ Identification of gauge incidences.
- ✓ Door side selective mode.
- ✓ Driver attention monitoring.
- ✓ Infrastructure monitoring.
- ✓ Accident prevention based on perception and inter-vehicle communications.
- ✓ Speed limit per section.
- ✓ Adaptive speed control.
- ✓ Automatic luminous and acoustic warning to pedestrians and other vehicles.
- ✓ Weather conditions report based on perception.
- ✓ Automated command of track switches.
- ✓ Adaptation of speed and consumption based on shared traffic lights.
- ✓ Signal identification and classification for decision making.
- ✓ Adaptation to route changes due to specific incidents.

3. SYSTEM DEFINITION AND OPERATIONAL CONTEXT

The ATO concept for tramways described in section 2 was taken as input for the Task 5.6 of R2DATO project resulting in a set of operational Use Cases [1] describing the operation of remote driving operations and autonomous operations in depot.

Deliverable 5.6 defines six use cases as a priority for the depot environment that covering and showcasing most of the functionalities of ATO systems, including remote driving, telecommand and autonomous operations. These use cases are:

Use case UC.5.6.5.24: Remote parking in a depot

Shunting in a tram depot is the process of moving trams between tracks or on the same track, usually for parking, maintenance, or washing purposes. Shunting may involve switching points, signals, and crossings to ensure the safe and efficient movement of trams within the depot. Application of ATO (both remote driving and autonomous operations) can address the following challenges: minimising the shunting time, optimising the track allocation, automating the routine operations, etc.

Use case UC.5.6.5.25: Remote washing

The operators identified a second opportunity, which involved the application of automation and remote-control technology to streamline the tram washing routines. This approach aimed to improve efficiency by allowing operators to control and monitor the washing process of exterior remotely. By implementing automation, they could enhance the overall reliability and precision of tram cleaning operations. Ultimately, this initiative sought to optimise resources and deliver a more cost-effective and consistent tram maintenance solution.

Use case UC.5.6.10.5: Pre-departure tram check

Pre-departure readiness encompasses diverse applications of ATO, including:

- Automated pre-departure checks: leveraging ATO to execute elements of pre-trip checks traditionally performed by tram drivers or depot personnel. One of the examples of such use cases is wheel profile examination (See the use case described below).
- Remote tram system control: enabling telecommand manipulation of tram systems such as doors, HVAC, and acoustic signals.
- Autonomous depot driving: facilitating autonomous tram movement within depots, fostering efficient tram deployment at the start of shifts.

Use case UC.5.6.2.3.1: Autonomous shunting (from indoor to outdoor)

This use case sets an advanced application of Tram ATO technology within a depot environment, specifically focusing on autonomous operations. In various scenarios, the requirement arises to perform vehicle shunting activities within the depot, such as transitioning from indoor (e.g., a shelter) to outdoor locations or moving from the maintenance workshop to a sheltered area. This use case also integrates considerations of weather conditions as a pivotal parameter for adjusting the vehicle's driving characteristics and enhancing tram responsiveness to account for increased braking distances.

Use case UC.5.6.2.2.1: Autonomous shunting of several vehicles simultaneously using V2X

The primary focus of this use case is vehicle management, specifically the replacement of an out-of-service tram with an operational one. This requires the implementation of V2X communication, which serves as a comprehensive framework for exchanging information among multiple trams and the surrounding infrastructure. It is important to note that, for this use case, the assumption is made that the depot's infrastructure is advanced enough to support these operations.

Use case UC.5.6.10.3: Wheel profile examination

The use case represents a specific maintenance procedure: laser wheel profile examination, showing the benefits of remote driving to optimise the examination process. With higher level of autonomy, the use case can be transformed to autonomous operation.

The previous six operational use cases, which are described in more detail in Section 6, have been taken as reference for the specification of the ATO architecture in tramways introduced in Section 7.

Apart from the six operational use case described above, Task 5.6 introduced some functional use cases for commercial areas:

Self-test functions

- More advanced self-test functions, e.g., clearing TCMS interface failures without driver involvement

Obstacle detection and speed adjustment:

- Detection of moving objects on the tracks
- Detection of moving objects along the trajectory that might lead to a collision
- Decision-making regarding speed adjustments

Automated acoustic signals

- Automated use of acoustic signals when needed

Real-Time Tram Positioning

- Real-time tram positioning on a line

Control of Speed

- Accelerating, decelerating and stopping

Signs, Signals, and Markings

- Detection of signs, signals, and markings, including temporary ones and those out of order
- Using a perception system to make decisions on speed adjustments in various weather conditions and times of the day

V2X Communication

- Detection and anticipation of signals via V2X protocols
- Detection and anticipation of the trajectory of other traffic users via V2X protocols
- Decision-making on speed and acceleration/deceleration in response to V2X communication

The logical functions employed for the ATO specification, along with the functional elements and interfaces comprising this architecture, must address these practical use cases.

4. RISK ANALYSIS AND EVALUATION

The methodology followed for the risk analysis and evaluation of the new ATO functionalities introduced in this document is based on the Concept definition presented in section 2 and the Operational Use Cases to be covered presented in section 3. From these two inputs, a Preliminary Hazard Analysis (PHA) will be presented in this section, which will result in a set of System Requirement Review (SRR) and Safety Related Application Conditions (SRAC). Both, SRR and SRAC, describe the measures to be taken to mitigate the unacceptable risks from PHA, being the SRR the requirements to be applied by the ATO system and SRAC the conditions to be fulfilled by other systems to ensure a safe operation.

The aim of the PHA is to define the appropriate safety measures that ensure:

(1) that all autonomous and remote manoeuvres are carried out safely within controlled areas.

(2) that the safety level is maintained with respect legacy tram platform when trams are released in passenger service with GoA2+ functions.

The hazards identified should be divided then whereas these hazards appear in autonomous, GoA4, movements in controlled areas or in GoA2+ movements, where a driver is present, in uncontrolled areas.

It is worth noting that the risk identified are the new ones taking a legacy tram platform as baseline, i.e. only new risks applicable to the introduction of remote driving and autonomous manoeuvres are considered.

EFFECT ON HAZARD IDENTIFIED FOR GOA

The introductions of these functions to a tram could lead to hazards summarized in Table 1:

ID	Hazard	Rationale	Scope
H-1.1	Excessive speed	Command to brake the tram not effective, leading to risk of collision with other trams, bump-stops or people.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-1.3	Carbody structural fault	Risk may arise if the carbody structure is modified to install new components.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-2.5	Unwanted movement while the vehicle is left parked switched on	Vehicle moves unannounced. Depot workers may not be aware that the tram was going to move. Potential collision with people.	Use on controlled area with GoA4.
H-2.6	Unwanted movement while the vehicle is left parked switched off	Vehicle turns on remotely and moves unannounced. Depot workers may not be aware that the tram was going to move. Potential collision with people.	Use on controlled area with GoA4.

ID	Hazard	Rationale	Scope
H-3.1	Tram travelling outside gauge	Components are installed in such a way that the gauge is compromised.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-3.2	Incorrect driver visibility	Cameras or obstacle detectors are installed in such a way that the visibility of the driver is reduced.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-4.1	No light and/or acoustic indication	Vehicle moves unannounced. Depot workers may not be aware that the tram was going to move. Potential collision with people.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-2.8B	Uncontrolled remote access	Related to cyber security. A new path is going to be implemented allowing remote control of the tram. A risk is introduced where remote access and driving is permitted to unauthorised people.	Passenger service with GoA2+. Use on controlled area with GoA4.
H-3.2B	Incorrect remote visibility	The visibility through the cameras is not good enough to make safe decisions. Possible causes: blurred image, insufficient resolution, image too dark, excessive lag, image freezing.	Use on controlled area with GoA4.
H-4.3B	Movement in the opposite direction to the one requested	The train moves in the opposite direction to the one selected. Hypothesis: only depot areas considered. No passengers on board.	Use on controlled area with GoA4.
H-20.1	Driving in GoA4 outside controlled area	Hazard occurs when train in GoA4 moves beyond the controlled area	Use on controlled area with GoA4.
H-20.2	Collision with obstacle in GoA4	The train collides with an obstacle in the controlled area. Possible causes: failure of obstacle detection system, lack of training, lack of depot procedures to clear tracks.	Use on controlled area with GoA4.

Table 1: Hazard analysis for GoA2 and GoA4 operations

Methodology for hazard classification

Hazards must be classified according to their severity and frequency. Hazards then are classified according to the region they belong according to the risk matrix. Unacceptable hazards need risk reduction measures.

Criteria for hazard classification

A risk matrix used in this risk analysis is presented in Table 2 to decide whether risk is acceptable or not.

Severity / Frequency	I- Catastrophic	II- Critical	III- Marginal	IV- Insignificant
A- Frequent	NA	NA	NA	AuA
B- Probable	NA	NA	AuA	AuA
C- Occasional	NA	NA	AuA	A
D- Remote	NA	AuA	A	A
E- Improbable	AuA	A	A	A
F- Incredible	AuA	A	A	A

Table 2: Risk matrix

Risk acceptability depends on the following criteria:

Risk Evaluation			Risk reduction / control
	Not acceptable	NA	Shall be eliminated
	Acceptable under agreement	AuA	Shall only be accepted when risk reduction is impracticable and with the agreement of the Railway Authority.
	Acceptable	A	Acceptable without agreement

Results for hazard classification

Severity and frequency are assigned to each hazard. All hazards are unacceptable without risk reduction measures.

ID	Hazard	Frequency	Severity	Assessment
H-1.1	Excessive speed	A (frequent, every time that the remote driving is used)	Catastrophic	Not acceptable

ID	Hazard	Frequency	Severity	Assessment
H-1.3	Carbody structural fault	A (frequent)	Catastrophic (if these trains are used in normal service, even if the remote driving is deactivated)	Not acceptable
H-2.5	Unwanted movement while the vehicle is left parked switched on	A (frequent)	Critical (collision with one person considered)	Not acceptable
H-2.6	Unwanted movement while the vehicle is left parked switched off	A (frequent)	Critical (collision with one person considered)	Not acceptable
H-3.1	Tram travelling outside gauge	A (frequent)	Catastrophic (if these trains are used in normal service, even if the remote driving is deactivated)	Not acceptable
H-3.2	Incorrect driver visibility	A (frequent)	Catastrophic (if these trains are used in normal service, even if the remote driving is deactivated)	Not acceptable
H-4.1	No light and/or acoustic indication	A (frequent)	Critical (collision with one person considered)	Not acceptable
H-2.8B	Uncontrolled remote access	A (frequent)	Catastrophic (if the train leaves the operationally controlled area)	Not acceptable
H-3.2B	Incorrect remote visibility	A (frequent)	Critical (no passengers in tram)	Not acceptable
H-4.3B	Movement in the opposite direction to the one requested	A (frequent)	Critical (no passengers in tram)	Not acceptable

ID	Hazard	Frequency	Severity	Assessment
H-20.1	Driving in GoA4 outside controlled area	A (frequent)	Catastrophic (the train leaves the operationally controlled area)	Not acceptable
H-20.2	Collision with obstacle in GoA4	A (frequent)	Critical (no passengers in tram)	Not acceptable

Table 3: Results for hazard classification

OUTPUT OF THE RISK ANALYSIS

Risk reduction measures are defined in the Preliminary Hazard Analysis. The aim of these risk reduction measures is to bring risk level to an acceptable region. To this avail, safety requirements are defined:

(1) Technical safety requirements, which are labelled as “SRR”.

(2) Operational and maintenance-related barriers, which are labelled as “SRAC”.

Hazard ID	Hazard text	Severity	Frequency	Scope	Initial evaluation	Cause ID	Potential cause	Mitigation measure type	Requirement code	Mitigation measure
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-1	Speed not limited automatically when remote driving	SRR	SRR-2001	Tram speed shall be calculated. Note that the tram's maximum speed shall be defined after evaluation of risks associated with particular operational rules of the operator.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-2	Dead man monitoring not effective.	SRR	SRR-2019	The dead-man function shall be extended to detect problems of communications as absence of remote driver.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-3	Remote driver unaware of tram speed	SRR	SRR-2002	The remote operator's DMI shall display the tram speed.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+.	Unacceptable	H-1.1 - C-4	Excessive lag of tram speed data shown to the remote desk	SRR	SRR-2003	Lag shall be calculated and displayed in the remote operator's DMI.

				Use on controlled area with GoA4.						
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-5	Failure of the positioning system, where maximum speed limit is not defined for the operationally controlled area.	SRR	SRR-2015	The tram shall command brake if the tram leaves controlled area or if exceeds maximum allowed speed.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-6	Driving not supervised	SRAC	SRAC-2007	Tests shall be performed with a test driver on board of the tram's cab, who shall supervise driving and command brake if needed to prevent collision or overspeed.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+.	Unacceptable	H-1.1 - C-6	Driving not supervised	SRR	SRR-2020	Local tram driver's actions shall always prevail over remote driving system's commands.
H-1.1	Excessive speed	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-7	Failure when migrating legacy tram functionality	SRR	SRR-2018	Migration of TCMS software shall be performed and documented. Non-regression of baseline tram functions shall be documented.

H-1.1	Excessive speed	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-1.1 - C-8	Wrong definition of journey and mission profiles with speeds above the maximum allowed speed	SRR	SRR-2023	The tram shall command brake if the tram exceeds the allowed maximum speed.
H-1.3	Carbody structural fault	Catastrophic	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-1.3 - C-1	Modifications to existing carbody structure or adding new supports.	SRR	SRR-2004	It shall be ensured that the modifications in order to install new components do not compromise structural integrity of the carbody.
H-2.5	Unwanted movement while the vehicle is left parked switched on	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-2.5 - C-1	Workers unaware of moving tram, cross in front of the tram.	SRAC	SRAC-2002	Remote tram driver shall request permission before moving the tram.
H-2.5	Unwanted movement while the vehicle is left parked switched on	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-2.5 - C-2	Tram moves uncommanded.	SRAC	SRAC-2010	It will be installed a mode selection switch which physically turns on/off autonomous movement equipment. Mode selection switch will only be set to “Autonomous mode” as long as a driver is on the cab or as long as security brake is applied.

H-2.5	Unwanted movement while the vehicle is left parked switched on	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-2.5 - C-3	Workers unaware of moving tram, cross in front of the tram.	SRAC	SRAC-2001	Access to tracks where the trams may move remotely or autonomously shall be restricted, in order to avoid untrained staff crossing tracks or on tracks where trams will be driven remotely or autonomously.
H-2.6	Unwanted movement while the vehicle is left parked switched off	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-2.6 - C-1	Tram turns on uncommanded.	SRAC	SRAC-2014	The trams have a remote wake-up module that enables the tram to be turned on with a remote command. Operational procedures shall ensure that the tram will not be turned on and moved unintentionally. Special credentials shall be needed to wake-up the tram remotely.
H-2.6	Unwanted movement while the vehicle is left parked switched off	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-2.6 - C-2	Workers unaware of moving tram, cross in front of the tram.	SRAC	SRAC-2001	Access to tracks where the trams may move remotely or autonomously shall be restricted, in order to avoid untrained staff crossing tracks or on tracks where trams will be driven remotely.
H-3.1	Tram travelling outside gauge	Catastrophic	A	Passenger service with GoA2+.	Unacceptable	H-3.1 - C-1	Added components out of gauge	SRR	SRR-2006	All components shall be installed within the tram gauge.

				Use on controlled area with GoA4.						
H-3.1	Tram travelling outside gauge	Catastrophic	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-3.1 - C-2	Temporarily added items damaged	SRAC	SRAC-2018	Temporary test installations shall be removed before washing /maintenance of trams units takes place. Relevant instructions shall be covered in test procedures for tests in which temporary installations are made.
H-3.2	Incorrect driver visibility	Catastrophic	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-3.2 - C-1	Added components obstruct existing driver's visibility.	SRR	SRR-2007	Added components shall not obstruct driver's visibility (local or remote).
H-4.1	No light and/or acoustic indication	Critical	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-4.1 - C-1	Workers unaware of moving tram, cross in front of the tram.	SRAC	SRAC-2002	Remote tram driver shall request permission before moving the tram.
H-4.1	No light and/or	Critical	A	Passenger service with GoA2+.	Unacceptable	H-4.1 - C-2	Workers unaware of moving tram,	SRAC	SRAC-2001	Access to tracks where the trams may move remotely or autonomously shall be

	acoustic indication			Use on controlled area with GoA4.			cross in front of the tram.			restricted, in order to avoid untrained staff crossing tracks or on tracks where trams will be driven remotely or autonomously.
H-2.8B	Uncontrolled remote access	Catastrophic	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-2.8B - C-1	Hacking of remote driving communications channel.	SRR	SRR-2008	Cybersecurity measures shall be put in place to avoid unauthorised remote driving.
H-2.8B	Uncontrolled remote access	Catastrophic	A	Passenger service with GoA2+. Use on controlled area with GoA4.	Unacceptable	H-2.8B - C-2	Remote driving desk post without access control.	SRAC	SRAC-2013	Physical access to remote control desk shall be controlled. Access to remote control logic shall be controller with credentials.
H-3.2B	Incorrect remote visibility	Critical	A	Use on controlled areas	Unacceptable	H-3.2B - C-1	Excessive lag	SRR	SRR-2010	Ensure real-time video stream. Lag should be estimated and reduced as much as possible.
H-3.2B	Incorrect remote visibility	Critical	A	Use on controlled areas	Unacceptable	H-3.2B - C-2	Frozen image	SRR	SRR-2011	Time stamp or equivalent technology to make remote driver aware of potential frozen image

H-3.2B	Incorrect remote visibility	Critical	A	Use on controlled areas	Unacceptable	H-3.2B - C-3	Low resolution	SRR	SRR-2012	Video stream must have enough resolution and quality to ensure that safe decisions can be taken.
H-3.2B	Incorrect remote visibility	Critical	A	Use on controlled areas	Unacceptable	H-3.2B - C-4	Too dark / not enough detail / inconsistent lighting	SRR	SRR-2013	The cameras shall produce video of sufficient quality in all foreseeable lighting situations.
H-3.2B	Incorrect remote visibility	Critical	A	Use on controlled areas	Unacceptable	H-3.2B - C-5	Excessive risk taking by remote driver	SRAC	SRAC-2003	The remote operator shall immediately command the tram to stop if the camera image does not provide enough quality to make safe decisions. For example, if there is excessive lag, too low resolution, image too dark to distinguish elements on screen.
H-4.3B	Movement in the opposite direction to the one requested by the remote desk driver.	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-4.3B - C-1	Wrong programming.	SRAC	SRAC-2004	Backwards movement shall be forbidden by TCMS in remote driving. The remote driver shall verify that the active cabin is the correct one before proceeding to move the tram remotely.
H-4.3B	Movement in the opposite direction to the one requested by	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-4.3B - C-2	Lack of coordination between OCC and remote operator	SRAC	SRAC-2008	A communication channel separate from the tram's devices shall be provided between OCC and remote operator. For example, a mobile phone or PMR.

	the remote desk driver.									
H-20.1	Collision with obstacle in GoA4	Catastrophic	A	Use on controlled area with GoA4.	Unacceptable	H-20.1 - C-1	Technical failure	SRR	SRR-2015	The tram shall command brake if the tram leaves controlled area or if exceeds maximum allowed speed.
H-20.1	Collision with obstacle in GoA4	Catastrophic	A	Use on controlled area with GoA4.	Unacceptable	H-20.1 - C-2	Operational failure: autonomous mode features not disabled outside controlled area.	SRAC	SRAC-2011	Before allowing dispatch for passenger service, it shall be ensured that the mode selection switch is in position “operation mode” and that the added devices are disconnected.
H-20.2	Collision with obstacle in GoA4	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-20.2 - C-1	Technical failure - EB3 not applied with obstacle on track	SRR	SRR-2021	The obstacle detection system and its parameters (how far it can detect obstacles, which type of obstacles, environmental influence on the system) will be characterised and confirmed with tests.
H-20.2	Collision with obstacle in GoA4	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-20.2 - C-1	Technical failure - EB3 not applied with obstacle on track	SRR	SRR-2022	The obstacle detection system shall apply EB3 to stop the train to avoid collision with an obstacle.
H-20.2	Collision with obstacle in GoA4	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-20.2 - C-2	Undetectable obstacles on tracks	SRAC	SRAC-2005	Depot procedures will ensure that no undetectable obstacles (such as toolboxes) are left on tracks.

H-20.2	Collision with obstacle in GoA4	Critical	A	Use on controlled area with GoA4.	Unacceptable	H-20.2 - C-2	Undetectable obstacles on tracks	SRAC	SRAC-2017	Movements in “Autonomous mode” within controlled area will be managed and planned to avoid unplanned obstacles on the tracks.

Table 4: Hazard log

The System Requirement Review derived from Hazard log is summarized in Table 5. This table includes the SRR allocation for logical functions explained in section 5.

SRR ID	Measure	Measure allocation
SRR-2001	Tram speed shall be defined after evaluation of risks associated with particular test procedure	Measure tram's speed Determine maximum authorised speed Monitor speed and distance
SRR-2002	The remote operator's DMI shall display the tram speed.	Measure tram's speed Provide video stream
SRR-2003	Lag shall be calculated and displayed in the remote operator's DMI.	Provide video stream
SRR-2004	It shall be ensured that the modifications in order to install new components do not compromise structural integrity of the carbody.	Structural calculation.
SRR-2006	All components shall be installed within tram gauge	Gauge calculation.
SRR-2007	Added components shall not obstruct driver's visibility (local or remote).	Visibility calculation.
SRR-2008	Cybersecurity measures shall be put in place in order to avoid unauthorised remote driving.	Cybersecurity plan and related tests.
SRR-2010	Ensure real-time video stream. Lag should be estimated and reduced as much as possible.	Provide video stream
SRR-2011	Time stamp or equivalent technology to make remote driver aware of potential frozen image	Provide video stream
SRR-2012	Video stream must have enough resolution and quality to ensure that safe decisions can be taken.	Provide video stream
SRR-2013	The cameras shall produce video of sufficient quality in all foreseeable lighting situations.	Provide video stream
SRR-2015	The tram shall command brake if the tram leaves controlled area or if exceeds maximum allowed speed.	Supervise runaway movement
SRR-2018	Migration of TCMS software shall be performed and documented. Non-regression of baseline tram functions shall be documented.	Software quality assurance plan.
SRR-2019	The dead-man function shall be extended to detect problems of communications as absence of remote driver.	Drive tram remotely
SRR-2020	Test tram drivers actions shall always prevail over remote driving system's commands.	Drive tram remotely

SRR-2021	The obstacle detection system and its parameters (how far it can detect obstacles, which type of obstacles, environmental influence on the system) will be characterised and confirmed with tests.	Detect obstacles
SRR-2022	The obstacle detection system shall apply EB3 to stop the train to avoid collision with an obstacle.	Detect obstacles Provide Brake Command for Emergency Braking
SRR-2023	The overspeed system shall apply EB3 to stop the train.	Measure tram's speed Provide Brake Command for Emergency Braking

Table 5: System Requirement Review

The Safety Related Application Conditions derived from Hazard log as well as the actor to whom it is export is summarized in Table 6.

SRAC ID	Measure	Exported to
SRAC-2001	Access to tracks where the trams may move remotely shall be restricted, in order to avoid staff crossing tracks or on tracks where trams will be driven remotely.	Operator
SRAC-2002	Remote tram driver shall request permission to test tram driver before moving the tram.	Operator
SRAC-2003	The remote operator shall immediately command the tram to stop if the camera image does not provide enough quality to make safe decisions. For example, if there is excessive lag, too low resolution, image too dark to distinguish elements on screen.	Operator
SRAC-2004	Backwards movement shall be forbidden by TCMS in remote driving. The remote driver shall verify that the active cabin is the correct one before proceeding to move the tram remotely.	TCMS
SRAC-2005	Depot procedures will ensure that no undetectable obstacles (such as toolboxes) are left on tracks.	Operator
SRAC-2006	Test tram driver and the remote operator shall know the controlled area perimeter, and they will not allow tram movement beyond controlled area	Operator
SRAC-2007	Tests shall be performed with a test driver on board of the tram's cab, who shall supervise driving and command brake if needed to prevent collision or overspeed.	Operator

SRAC-2008	A communication channel separate from the tram's devices shall be provided between OCC and remote operator. For example, a mobile phone or PMR.	Operator
SRAC-2010	It will be installed a mode selection switch which physically turns on/off autonomous movement equipment. Mode selection switch will only be set to “Autonomous mode” as long as a driver is on the cab or as long as security brake is applied.	Operator
SRAC-2011	Before allowing dispatch for passenger service, it shall be ensured that the mode selection switch is in position 0 or 1 and that the added devices are disconnected.	Operator
SRAC-2013	Physical access to remote control desk shall be controlled. Access to remote control logic shall be controller with credentials.	Operator
SRAC-2014	The trams have a remote wake-up module that enables the tram to be turned on with a remote command. Operational procedures shall ensure that the tram will not be turned on and moved unintentionally. Special credentials shall be needed to wake-up the tram remotely.	Operator
SRAC-2017	Movements in “Autonomous mode” within controlled area will be managed and planned to avoid unplanned obstacles on the tracks.	Operator
SRAC-2018	Temporary test installations shall be removed before washing /maintenance of trams units takes place. Relevant instructions shall be covered in test procedures for tests in which temporary installations are made.	Operator

Table 6: Safety Related Application Conditions

5. SPECIFICATION OF SYSTEM REQUIREMENTS

The specification of the system requirements for autonomous manoeuvres and remote driving for tramways is introduced in this chapter. For the system specification, and in terms to use similar definition and taxonomy as in ATO architecture for mainline, the list of logical functions produced by X2Rail-4[1] has been taken as a reference. This list of logical functions has been transferred to tramway domain, removing those which are not applicable in such domain and rewriting others to translate them to the actors and operations of tramways.

DESCRIPTION OF LOGICAL FUNCTIONS

This section covers the logical functions needed to operate a tramway. For the shake of clarity, the list of logical function has been grouped in eight clusters as illustrated in Figure 2. These clusters are:

- **Tram Preparation:** This cluster groups all functions related to the preparatory works to be made in the unit by the driver, maintenance staff or Operation and Control Centre before the tram is assigned to a service or to recover it in case of failure.
- **Tram Subsystem Management:** This cluster groups all logical functions tackling with tram subsystems. Most of these functions are made via Train Control and Monitoring System (TCMS) by a driver or an Automatic Train Operation (ATO) module.
- **Monitor Tram conditions:** This cluster groups all logical functions that monitor the tram status during operations or maintenance tasks and report to driver or to Operation and Control Centre (OCC) the condition of different tram elements to ensure the correctness of the tram unit.
- **Perception:** This cluster groups the logical functions related to the detection of the tram condition with its surrounding elements. They serve to detect events that could cause a non-desired operational condition. Traditionally, they are made by the tram driver or operator staff using its senses.
- **Tram movement:** This cluster groups the logical functions related to tram movement in depot, shunting and operation. These functions include not only the traction and bake functionalities but also the management of speed limits, adhesion management, stopping points itinerary and provide relevant information to the driver about itinerary among others.
- **Communications with Passengers:** This cluster groups the functions tackling with the communications between the passengers and the Operation and Control Centre (OCC) or the Driver.
- **Events Management:** This cluster groups functions related to unexpected events that could happen within the tram unit and in the track close to the tram's position, as well as the actions taken to address them.
- **Infrastructure Data Management:** This cluster groups the functions to update the infrastructure information which may affect tram operation.

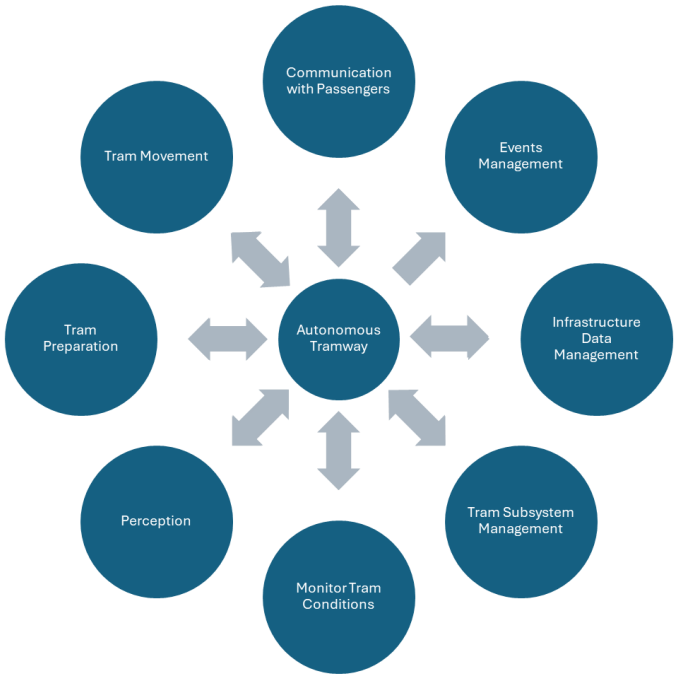


Figure 2: Logical functions clustering

TRAM PREPARATION

#1 Check-out/Check-in vehicle

Check-out means that the tram is configured with the physical switch which allows remote driver to take the control.

Check-in means that the tram is configured with the physical switch which does not allow the remote driving. The Onboard Remote Driving function is off.

#10 Schedule routine maintenance

In this function, the entity in charge of maintenance plans maintenance activities of the trams and informs a tram fleet manager.

#11 Organize recovery

In this function, an Emergency Manager takes all actions necessary to put again the service in normal operation.

#14 Attribute a trainset to a mission

In this function, a Fleet Manager assigns a tram or trainset from his fleet to the planned mission.

#17 Dispatch orders

In this function, OCC transmits the following orders:

- Authorization to proceed
- Authorization to close doors (door closing can be delayed for a person with reduced mobility or forced in case of crowd)
- Start prohibited

- Tram immobilization
- Vehicle battery protection.

#22 Authorise Staff Responsible movements

In this function, an operator authorizes a movement of a tram in Staff Responsible mode, bypassing ATP/ATO/IPM to move it remotely or in person.

#25 Set routes

In this function, an Operator interfaces with a Train Management System to set routes for trams.

#32 Be identified like an autonomous tram

In this function, Physical Tram Unit activates a specific light to identify the tram as an autonomous one.

#46 Sense catenary voltage

This function measures catenary voltage for pantograph monitoring purpose.

#47 Provide charging

This function provides energy to a battery and reports an anomaly in case of charger default.

#50 Protect collection devices and catenary

This function protects against use of high voltage when maintenance or cleaning operations are performed on the tram.

#51 Provide tram radio information

This function manages tram radio information when this device is present. It changes the channel of the voice radio communication system when requested and sends vehicle radio alarm. Trams typically use Professional Mobile Radio (PMR) such as Terrestrial Trunked Radio (TETRA).

#52 Manage electrical energy for traction

This function activates the raise/lower pantograph commands and switches on/off the main circuit breaker when requested.

#54 Provide Test (Emergency Brake)

This function tests effective application of the emergency brake command.

#56 Manage uncoupling

This function manages the coupling/splitting when requested.

#58 Provide low voltage DC supply

This function switches on/off the low voltage contactors from battery when requested.

#59 Define a mission

In this function, an Operator defines the missions of a tram. For each mission, the sequence of tasks is elaborated.

#61 Request video

In this function, an Operator requests a video stream of tram environment to support remote control operation.

#63 Manage energy supply for auxiliaries

This function switches on/off power supply of auxiliaries (HVAC, lights, battery, compressor...) when requested i.e. tram preparation.

#65 Inaugurate tram network

This function performs the tram inauguration (automatically made by TCMS) to determine tram configuration (count, order, direction and capabilities of the consists). Only for coupled units.

#73 Provide remote control

This function gives access to TCMS for remote control.

#75 Manage control of the tram parameters

This function controls the following tram parameters:

- Braking capacity
- Tram mass
- Obtained braked weight
- Tram composition
- Tram parameters
- Vehicle type
- Tram category
- Maximum tram speed
- Tram length

#77 Manage appropriate and safe conditions

This function controls comfort and safety functionality.

#78 Maintain tram physically immobilized

This function is performed today by a driver or a tram attendant with the installation of stop shoes on the wheels.

#79 Request brake test

In this function, Tram Preparation Staff requests ATO or driver to perform a brake test on a tram.

#80 Request coupling

In this function, Tram Preparation Staff or driver requests a coupling operation for trams.

#81 Request tram wake-up

In this function, Tram Preparation Staff requests the wake-up of a tram.

#82 Request tram hold

In this function, Tram Preparation Staff requests the tram immobilization by the system and informs when intervention on the tram is finished.

#83 Determine brake test to trigger

In this function, Tram Preparation Staff determines the brake test to trigger and communicates this information to the system.

#84 Request brake release

In this function, Tram Preparation Staff requests ATO to release the brakes.

#85 Remove Stop shoes

The stop shoes are used in parking in depot in case of failures of the tram's brakes.

#86 Set Stop shoes if necessary

The stop shoes are used in parking in depot in case of failures of the tram's brakes.

#90 Supervise service brake efficiency during operation

This function checks effective deceleration of the service brake.

#97 Determine ATO state

This function manages transitions between different ATO modes of its internal state machine.

#110 Manage supervision orders

This function receives direct orders from the operator for remote control.

#114 Manage mission execution

This function loads a mission or a change of mission, checks it and computes the awakening sequences of ATO and tram to be ready on time. It defines the sequence of tasks to be executed (uncoupling, coupling, brake test, service retention, awakening and shutdown of a tram), monitors the correct sequencing and records data related to the different tasks.

#115 Start coupling

This function activates the tram coupling process where an automatic coupling operation is foreseen in the mission.

#116 Start splitting

This function activates the tram uncoupling process where an automatic splitting operation is foreseen in the mission.

#130 Command pantograph and main switch

This function detects that the tram is on a track location where it is necessary to cut the current or lower the pantograph according to the track conditions and generates the corresponding orders.

#131 Supervise emergency brake chain test

This function tests the emergency brake chain.

#138 Calculate all possible itineraries

This function calculates all possible itineraries between the start and the stop point of a tram movement configured with or without allocated path. The function extracts relevant information from infra database and records it.

#145 Determine/verify and transmit JP data

This function provides Journey Profile to ATO-OB after check of its consistency.

#146 Determine/verify and transmit MP data

This function provides Mission Profile to ATO-OB after check of its consistency. If Mission Profile (MP) applicable, the MP defines the mission for a given time and can involve multiple JPs, apart from awaking, Cab selection, etc.

#147 Receive anomalies in task or mission execution

This function receives the anomalies associated to a specific task or mission.

#148 Provide vehicle database

This function records all information related to vehicles in a database that can be shared between different users and updated with authorized access. The operator manages the vehicles planned for the missions and delivered by the Fleet Manager.

#155 Determine mission data

This function determines the mission to be sent to a given tram to satisfy the customer needs considering the technical constraints (e.g. restriction on rolling stock).

#156 Request tram's wake-up

This function orders a tram's awakening.

#157 Manage Entity in Charge of Maintenance request

This function transfers the responsibility of the tram to Entity in Charge of Maintenance (ECM) when requested and when the tram is parked on a maintenance yard (applicable when ECM is a third party independent to Operator or independent department within the operator organization).

#159 Forbid start

This function informs Operator about a Tram Preparation Staff intervention in order to inhibit the tram departure. Inhibition is removed at the end of intervention.

#161 Provide remote control

This function gives access to TCMS for remote control. The operator has access to this mode in degraded situations and/or depot operations for moving the trams on a limited distance at low speed. Note: In this remote-control mode, TCMS acts directly on traction and brakes (bypassing of Train Protection or ATO commands).

#162 Provide video stream

This function transmits a video stream of the tram environment on operator request. Video streams come from the video cameras used for remote driving.

#163 Manage Remote Driver request

This function transfers the responsibility of the tram to Remote Driver when requested.

#165 Register autonomous tram unit

This function receives the ATO identity record of each autonomous tram, checks it against the tram composition foreseen in the mission (consistency with vehicle database), records it and sends related information to the operator.

#167 Determine dynamic brake test time and location

This function determines the time and location for requesting a dynamic brake test within the authorized areas.

#168 Supervise tram wake-up

This function is associated to the TCMS state machine and requests tram awakening on demand of the Train Management or Driver or Tram Preparation Staff in a time window planned in the mission.

#177 Manage Tram Preparation Staff request

This function transfers the responsibility of the tram to the Tram Preparation Staff when requested and when the tram is parked on a shunting yard.

#178 Manage Remote Driver request

This function transfers the responsibility of the tram to Remote Driver when requested

TRAM SUBSYSTEM MANAGEMENT

#3 Manage doors (driver)

This function opens/closes doors of the tram. It also checks whether the passenger transfer in and out the tram is finished.

- Confirm that passenger exchange is finished (it is safe to start)
- Unblock doors (clean sensor/camera, remove obstacle)
- Estimate the impact of a door problem, depending on the TCMS alarm category, to decide whether the service can continue.
- Disable/enable doors in case of door problem.

#27 Command doors opening

In this function, a Passenger opens the doors unlocked by TCMS.

#29 Blocking door opening

Doors blocked at some short platforms.

#38 Release external doors

This function releases the door when requested and when the tram is at a standstill and within a station platform.

#39 Open external doors

This function opens the external doors of a tram when requested. Depending on configuration, doors can be opened by passengers.

#40 Close external doors

This function closes the external doors of a tram when requested.

#41 Manage door system upon an obstacle

This function detects an obstacle during door closing.

#57 Signal external door status change/open/close

This function activates the buzzer and lights of an intelligent door system when requested.

#64 Manage climatization

This function switches on/off a heating, ventilation and air-conditioning system when requested.

#66 Manage windscreen cleaning

This function switches on/off the wipers when requested.

#67 Manage exterior lighting

This function switches on/off the front and rear lights of the tram when requested and reports an anomaly when a light failure is detected.

#68 Manage the bell

This function activates and deactivates the bell.

#69 Manage tram modes

This function manages the transitions between TCMS modes.

#70 Manage cab control

This function controls the cab and its functionality. A specific action from the driver is necessary to unlock the driving desk and take control of the traction brake controller.

#71 Manage isolation of devices

This function permits to isolate a specific function of TCMS.

#72 Manage interior lighting

This function activates the lights inside a tram when requested.

#98 Inhibit sanding

This function assures that sanding is not used when a tram is on a section where sanding is prohibited. It reads the sanding suppression sections contained in the Segment Profiles and compares them to the tram current estimated front end and rear end, which are derived from front end and tram length, to command the start or end of sanding suppression to TCMS.

#99 Start door closing sequence

This function is tram dependent and starts the door closing sequence when dwell time has elapsed.

#117 Command and supervise horn

This function commands the horn at specific infrastructure locations, tunnel entry/exit or when persons are detected on or near the track. In general horn is only used in operation when there is a danger.

MONITOR TRAM CONDITIONS

#8 Manage reporting

This function manages reporting to an infrastructure manager and/or tramway operator regarding the tram's health condition and/or changes to physical railway environment such as the adherence conditions.

#19 Ensure monitoring of a running tram

An Operator monitors running of trams in a network via Traffic Management and manages incidents affecting operation (e.g., hot axle, traction failure...).

#62 Supervise trams

In this function, an Operator must evaluate impact of tram's anomalies on the planned mission and remove related alarms when relevant. The operator can also prohibit the tram departure and unlock the immobilization status after a conflict resolution.

#102 Monitor fire alarm

This function monitors the fire alarm. Currently this function is performed by a tram driver.

#103 Monitor alarm signal

This function supervises the passenger alarms: call for help button and emergency request.

#104 Monitor derailment

This function detects derailment occurring on a tram by monitoring relevant on-board parameters with an acceptable reliability in any allowable service condition.

#105 Monitor tram unit failures

This function collects and combines the failures affecting a tram unit that can have an impact on operation.

#106 Monitor TIS status

This function monitors the Transport Information System status for reporting anomalies and possible isolation in case of occurrence.

#107 Monitor pantograph

This function detects and reports anomalies on the catenary (or other contact lines) that are so strong that they inhibit the tram to run safely over it.

#108 Monitor loss of voltage or low voltage

This function performed by TCMS monitors catenary voltage to detect a loss of voltage or a low voltage.

#112 Monitor battery protection mode

This function monitors the battery power level and requests TCMS to enter in battery protection mode if level is too low or when requested by operator.

#134 Measure tram's speed

This function measures tram's speed and provides current speed information (including standstill information).

#135 Provide UTC time

This technical function provides UTC time received from GNSS receiver.

#144 Receive status report

This function receives tram location, tram health status, current TCMS state of the tram and requests a new Journey Profile to TMS when an anomaly is detected by the tram.

#151 Track tram units

This function receives the position of the tram units and the tram data when there is a start of mission using safe position telemetry.

#158 Monitor trams

This function monitors trams and requests specific TCMS actions when requested.

#169 Transmit driving anomalies

This function reports anomalies related to the tram movement. E.g. driving anomalies, misrouting detected, grip/ground adhesion problem, stopping anomalies.

#171 Transmit periodically tram's location

This function transmits periodically tram location.

PERCEPTION

#2 Detect obstacles

This function detects the presence of obstacles and/or persons in the track and in the adjacent areas.

#16 Display signal

This function displays a signal to a Driver in the HMI, e.g. maximum speed.

#76 Manage surveillance system

This function gives access to tram interior images on request from an Operator.

#101 Check if the surroundings (except signalling) oppose the departure

This function checks if the information received from Perception does not inhibit the departure of the tram.

#111 Monitor weather conditions

This function monitors weather conditions: temperature/percentage of water/wind. Trackside weather forecasts are a starting point to derive driving restrictions from weather conditions.

#118 Detect sparks on a tram's roof

This function is optional and reports a traction problem on a crossing tram when it detects abnormal sparks on its roof.

#119 Detect person struck by a tram

This function monitors Physical Environment to detect a person struck by the tram. The person should be detected before a hit.

#120 Detect a hand signal or a red light flare

This function detects emergencies communicated by railway agents with a hand signal or a red light flare. It is used in case of emergency situations in tramway operations.

#121 Detect fire or heavy smoke on embankment

This function detects fire or heavy smoke on embankment and provides a fire description to initiate a reaction.

#122 Detect light failure on a tram's unit on the same track

This function senses the Physical Railway Environment to detect possible presence of vehicles on the same track and check the status of their front or rear light.

#123 Detect light failure on a crossing tram's unit

This function senses the Physical Railway Environment to detect possible presence of vehicles on the opposite track and check the status of their front or rear light.

#124 Detect crossing tram

This function monitors the tram environment to detect the presence of a tram running in the opposite direction on an adjacent track.

#125 Detect anomalies on a passing tram

This function detects the anomalies of the passing tram during operation. Currently this function is made by the tram driver and includes external anomalies such as the detection of sparking in the pantograph and problems in the external lighting on the passing tram.

#126 Detect level crossing damage

This function detects failures on a level crossing (a broken barrier, for example).

#133 Localize vehicle (track/direction/position/heading)

This function localizes the tram on infrastructure.

#136 Interpret lineside signalling including vertical signs

This function is currently performed by the tram driver. The interpretation of the lineside signalling includes the correct interpretation of tram-specific signalling in a depot and in operation and the vertical signalling of other vehicles sharing platform in operation.

#166 Interpret semaphore phases

This function retrieves the semaphore phases and process it providing the information to the driver via Driver Advisory System (DAS) or to the ATO.

#172 Monitor tram interior

This function monitors tram interior and informs operator in case of climate failure, inappropriate passenger behaviour, suspicious luggage or broken window.

#173 Detect abnormal passenger behaviour

This function detects a tram's interior anomaly, a passenger inappropriate behaviour or a suspicious luggage.

#174 Detect presence of passengers

This function detects a tram's interior anomaly, the presence of passengers inside the tram at the end of a passenger service.

#175 Detect railway agents on or along the tracks

This function senses the Physical Railway Environment to detect the possible presence of railway agents on or along the tracks, as well as authorized personal allowed to be or work in or near tracks.

#176 Detect vehicle or buffer stop on the same track

This function senses the Physical Railway Environment to detect the possible presence of vehicles on the same track.

TRAM MOVEMENT

#4 Manage journey

This function manages the journey to determine if the tram stops at a next stop or if it skips it.

#5 Perform shunting

This function performs shunting operations with the instructions of the Tram Preparation Staff.

#6 Stop precisely in station

This function checks if the tram has stopped in the designated place at a stop. In case the tram stops before the desired position the tram will move forward. In case the tram surpasses the desired position, the tram may take different decisions:

- Apply ASDO to open only doors within the platform.
- Change cabin to opposite direction and move back, but forwards, the tram and stop within the platform.
- Request explicit permission to the OCC to move backwards.

Comparing to other vehicles with dedicated platforms, in tramways pedestrians could be crossing the platform when the tram moves back.

#7 Drive a tram

In this function the driver drives tram manually ensuring the following points:

- control traction and brakes
- Obey to signalling (e.g. speed limit)
- Follow driving constraints (imposed speed limit)
- Follow emergency orders.
- Adjust driving style according to driving conditions (e.g. weather, light, traffic condition around)

In GoA2 the tram runs automatically from a stop to a stop but a driver is present in the cab, with responsibilities for door closing, detecting obstacles on the track in front of the tram and handling of emergency situations (e.g. open all doors and easy evacuation of the unit).

#9 Drive a tram remotely

In this function, a remote driver controls a tram remotely.

#12 Manage power demand

In tramway systems the power supply of the catenary is constant, and the number of tram units are limited by the OCC to do not have over requested power supply.

#21 Manage temporary speed restriction

An Operator can impose a temporary speed restriction that will be sent to a tram.

#24 Manage track adhesion

In this function, an Operator manages slippery rail information.

#33 Provide Brake Command for Parking Braking

This function applies or releases parking brakes.

#34 Provide acceleration

This function controls traction.

#35 Provide Brake Command for Service Braking

This function applies or releases the service brakes.

#36 Provide Brake Command for Holding Braking

This function applies or releases the holding brakes.

#37 Acquire realised braking effort

This function acquires the realised brake effort.

#48 Detect sliding

This function detects and react against slipping during traction and skidding during braking. This function also detects flat wheel.

#49 Command sanding

This function delivers sand on the track when requested.

#53 Provide Brake Command for Emergency Braking

This function receives the emergency brake command and triggers it.

#55 Apply and release braking forces

This function applies or releases the braking effort:

- Generate braking forces by friction brake
- Generate braking forces by eddy-current brake
- Generate braking forces by magnetic track brake
- Command electrodynamic brake
- Release braking forces (including emergency release).

#88 Check ad hoc brake release

Equivalent function in trams to release holding brake.

#89 Stop exactly at the intended location

This function finalizes the computation of the optimized target speed curve for regulation. It is possible to define two stopping points with one Timing Point for stop and one Timing Point for departure to manage crowd issues.

#91 Calculate expected braking effort

This function computes the needed braking effort for a specific tram, gradient of the track, climatic conditions, and breaking capability.

#92 Respect Journey Profile Timing Points and Optimize the consumption

This function provides the reference curve to be applied for respecting the Timing Points of the Journey Profile.

This function optimizes driving and braking strategy in order to run the tram as energy efficient as possible while respecting the intended timings and the infrastructure constraints.

#93 Control initial traction effort

This function controls initial traction effort of a tram according to the expected traction force.

#94 Calculate expected traction effort

This function computes the expected traction force according to a specific tram, gradient of the track, climatic conditions, and traction capability.

#95 Determine maximum authorised speed

This function computes a maximum speed curve applicable to the tram (maximum speed without warning activation) based on the tram location, the deceleration capacity of the tram, the maximum speed profile, the gradient profile, the tram category (maximum speed authorized for this tram) and the maximum speed authorized by the environmental constraints, if any.

#96 Regulate traction and braking effort

This function regulates traction and brakes (pneumatic brakes or electric brakes) depending on regulation parameters when immobilization brake is not activated. The target speed curve is derived from the optimized speed curve. The speed regulation should be smooth, not abrupt, as passenger comfort must be considered.

#100 Detect that final stopping point has been reached

This function informs when the tram has reached its final stopping point (End of Journey).

#109 Manage traffic priority for trams in mixed intersections

This function interacts with traffic light system of the city to provide to the tram a green corridor or priorities.

#113 Change running direction

This function determines from the Journey Profile the scheduled direction of movement and based on that the cab / front end to be activated.

#127 Manage communication exchanges with driver

This function acquires the inputs from the driver and displays information relevant for him.

#128 Monitor speed and distance

This function monitors the speed of the tram versus its position, in order to assure that the tram remains within the given speed and distance limits.

#129 Supervise runaway movement

This function supervises standstill, roll away and reverse movement.

#132 Monitor Emergency Brake distance

This function monitors the effective deceleration of the tram when emergency brakes are applied. The deceleration measurements permit to detect a possible failure of emergency brake. This function is currently made by the driver in test track and ensures that the tram stops within a section of the test track.

#137 Inform IM about prolonged stop

This function informs the operator that the tram is stopped in rear of a closed signal after a defined delay.

#140 Transmit supervision orders

This function transmits direct orders from the operator to Train Control and autonomous tram.

#149 Transmit Emergency Stop

This function transmits Emergency Stop message to onboard IPM. Emergency pantograph drop can also be requested.
In case of GoA2+ this belongs to driver.

#150 Transmit TSR

This function transmits Temporary Speed Restriction (TSR) to onboard ATO-OB and IPM.

#152 Manage traffic

This function operates the trams automatically and interfaces with Operations Manager for specific actions.

#153 Manage stopping points and passing points

This function elaborates the Journey Profile according to the stops requests from an operator and any modification triggered due to a trackside of tram incident.

#164 Process remote driving commands

This function activates the cab for remote driving and processes the remote driver commands. In case of loss of communication, the function will apply emergency brakes.

#179 Command Emergency Brake

This function requests emergency brake application when decided by Driver or IPM.

COMMUNICATIONS WITH PASSENGERS

#28 Trigger passenger alarm

In this function, a Passenger triggers an emergency request or pushes the call for help button.

#30 Speak and listen

In this function, a Passenger is in communication with the OCC.

#87 Give visual and audible indication to passengers (in tram)

This function elaborates travel information to passengers on-board the tram.

#160 Ensure communication with passengers

This function permits operator to establish communication with onboard passengers:

- Incidents via Train Information System (TIS)
- Video link for analyzing situation
- Verbal communication if necessary.

#170 Transmit information to TIS

This function sends journey information to on-board passengers via the Transport Information System.

#45 Provide passenger emergency intercommunication

This function ensures verbal communication between passengers and the OCC

#60 Communicate with passengers

In this function, an Operator can communicate with passengers (verbal communication + specific messages for TIS) and monitors tram's interior via a closed-circuit television.

#142 Transmit incidents to PIS

This function transmits incidents to passengers via ATO-OB and Transport Information System.

EVENTS MANAGEMENT

#13 Manage energy demand

In this function, an Energy Manager interacts with an Infrastructure Manager to shutdown the catenary power in case of an incident or to restart a tram when it has been blocked in a de-energised section.

#18 Request protection against high voltage switch on

In a depot and restricted from general public areas a driver and depot staff must identify the power on/off signs to carry out some functions (e.g. works in the roof of the tram unit). This signalling comes from the depot or infrastructure manager.

In Operations the power on/off must be managed via Traffic Management and Infrastructure Manager.

#20 Solve conflicts

An Operator can inhibit automatic train operation (ATO) for solving conflicts where appropriated. For example, he can cancel a planned route before setting another one.

#23 Take initial actions in case of emergencies

In this function, an Operator manages emergencies at the first level (e.g., send emergency stop command to a tram or switch off catenary voltage).

#26 Request catenary power shutdown

With this function an Operator can request automatic shutdown of the catenary power in case of specific anomalies detected by a tram.

#31 Trigger events

This function models all events related to Physical Environment that must be detected by the system to trigger an appropriated action. Outputs:

- Luggage in a tram
- Passenger inside a tram
- Vehicle on track
- Railway agent
- Abnormal noise
- Sparks on a roof
- Flooding
- Track anomaly
- Animal wandering
- Catenary anomaly
- Body discovered
- Flooding (adjacent track)
- High level of snow in track
- Track anomaly (adjacent track)
- Level crossing damage
- Catenary anomaly (adjacent track)
- Crossing tram anomalies
- External fire
- Maintenance Staff presence signal
- Tram body dynamic
- Axle rotation at low speed
- Incident caused by the tram
- Passenger behavior
- Crossing tram in approach
- Crossing tram anomalies
- Uncontrolled tram
- Tram side anomaly
- Strucked person

#42 Manage signalling of fire

This function ensures management of a fire alert, fire warning and a notification of fire.

#43 Manage/Provide fire extinguishment

This function extinguishes fire when requested (sprinkler system, for example). This function does not exist currently in trams.

#44 Manage emergency alarm from passengers

This function detects the passenger alarms: call for help button and emergency request.

#74 Assist troubleshooting

This function is linked to Provide diagnostics and reports tram anomalies that can have an impact on operation.

#139 Manage trackside incidents

This function interfaces with Operation Manager to manage trackside incidents.

#141 Manage tram incidents

This function interfaces with Operation Manager to manage tram incidents.

#154 Protect from high voltage switch on

This function transmits the high voltage protection status.

INFRASTRUCTURE DATA MANAGEMENT

#15 Manage infrastructure database

In this function, an Infrastructure Manager updates an infrastructure database with a status of infrastructure and temporary constraints (TSRs, Protections, Work Zones...).

#143 Provide infrastructure database

This function records all information related to infrastructure in a database that can be shared between different users and updated with authorized access.

6. FUNCTIONAL USE CASES FROM OPERATIONAL USE CASES

This section defines the functional use cases for autonomous operations for tramways. In order to define these use cases, the operational use cases defined in the Task 5.6 [1] have been taken as a reference and each operation use case have been linked to the logical functions (described in section 5) needed to deploy it. Moreover, each functional use case has been defined as a sequence diagram to reflect the iteration between different actors in remote control/driving and autonomous movements. Lastly, from the iterations of those sequence diagrams the interfaces between different actors are defined.

FUNCTIONAL USE CASE FOR REMOTE PARKING IN A DEPOT

Operational use case for Remote parking in a depot

Table 7 summarizes the operation use case for remote parking in a depot and it was defined in R2DATO Task 5.6 [1].

Use case field	Description	
ID	UC.5.6.5.24	
Use case name	*Remote parking in a depot*	
Main actor	*Tram remote driver-operator (remote operator)*	
Other actors	• *Control centre operator or operations management room (at the depot) (OCC)* • *Supervising system* • *Depot personnel*	
Use case summary	*This use case involves the OCC granting permission to a remote operator to park a tram remotely on a vacant track and spot. The remote operator connects to the tram, selects the destination track and spot, commands the tram to move at shunting speed, and monitors the tram's movement until it reaches its final position and comes to a stop.*	
Applicability	• *Geographical: Europe* • *Operational category: Urban*	
Main goal	*The primary objective of this use case is to park a tram safely and efficiently on a designated depot track and spot using remote control while adhering to all safety and operational rules.*	
Preconditions	• *The tram is in a ready state for remote operation.* • *Communication between the remote-control centre and the tram is established.* • *Supervising systems (both onboard and trackside) are activated.*	
Termination outcome	**Successful outcomes**	• *The tram is successfully parked in the designated position.* • *All communications and systems are properly deactivated.*

	Unsuccessful outcomes	• *Communication failure between the remote-control centre and the tram.* • *Safety violations or faults detected during tram movement.*
Condition affecting termination outcome	**Outcome 2**	• *If communication fails, the tram may need to make repeated attempts to reconnect, following the operational rules of the network operator.* • *Safety violations or faults must be reported to the OCC.*
Use case scenario	**Step 1**	*The tram is locally started up. Tram systems are powered on, and initial checks are performed to ensure readiness for remote operation.*
	Step 1.1	*Initial checks reveal system failures, preventing remote driving. The operation cannot proceed successfully, and appropriate actions, such as reporting the issue and halting the operation, must be taken.*
	Step 2	*The remote operator initiates the remote driving mode, selecting the specific tram vehicle to be moved remotely and configuring the desired route and destination. They then contact the OCC to confirm the procedure. After receiving confirmation, the OCC manages motorized points along the route, allowing the remote operator to proceed with the next steps.*
	Step 2.1	*If confirmation of communication receipt is not If the remote operator does not receive confirmation of communication receipt from the OCC, they must halt further actions and attempt to reconnect with the OCC following the network instructions.*
	Step 3	*The remote operator activates the tram's onboard sensors, included in the perception system, and initiates video streaming. This step ensures proper visibility by verifying elements such as window cleanliness, camera views, and defrost functions.*
	Step 3.1	*If proper visibility is not ensured, a manual check must be performed, and Step 3 must be repeated.*
	Step 4	*The remote operator performs a pre-driving self-check on the tram following instructions for tram preparation for moving trams inside or outside the workshop, ensuring safety and operational readiness. They check remotely for:* • *Power is on.*

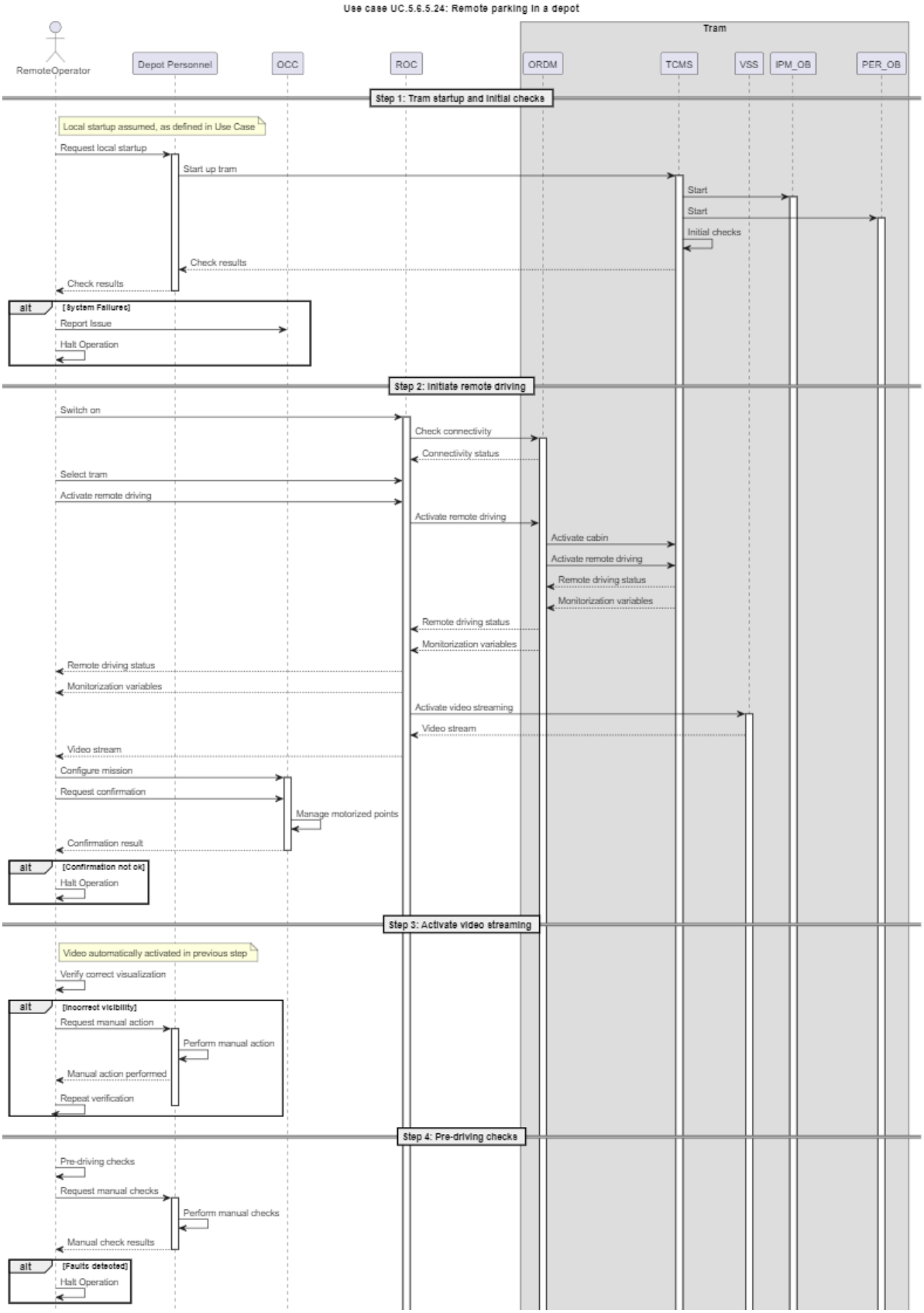
	• *Red light is illuminated.* • *The crane is not in the way (via cameras).* • *No person is working on or near the tram (via cameras).* • *The tram is not coupled to another tram.* *Checked manually by the depot personnel:* • *No scotches (stop shoes) under wheels.* • *Body catchers are raised.* • *All panels are secured.*
Step 4.1	*Any defects or faults identified during this check are reported to the OCC immediately. The use case is not further performed.*
Step 5	*The remote operator verifies the current position of the tram and attentively observes its surroundings through video cameras while checking sensors.*
Step 6	*After making sure supervising systems are activated, the remote operator chimes (or using a bell) remotely and commands the tram to start moving. The operator uses remote controls to manage the tram's speed and maintain a safe following distance. Continuous monitoring of the tram's movement is performed, with real-time feedback from sensors, cameras, and communication systems. The maximum speed does not exceed the shunting speed.*
Step 6.1	*If the operator notices an object on the tracks that prevents the completion of the route, they must initiate braking or emergency braking, depending on the situation. If the remote operator does not perform this procedure, the system initiates automatic emergency braking. After the obstacle is removed, the remote operator must repeat Step 6.*
Step 6.2	*If the obstacle is not removed or not possible to remove, the remote operator must contact OCC to follow the instructions.*
Step 7	*The remote operator checks signal statuses and signs using the cameras, adjusting speed, or applying brakes when necessary.*
Step 8	*When the tram's parking spot is inside the workshop, the remote operator, using the remote control, stops before the door, chimes remotely, checks for obstacles*

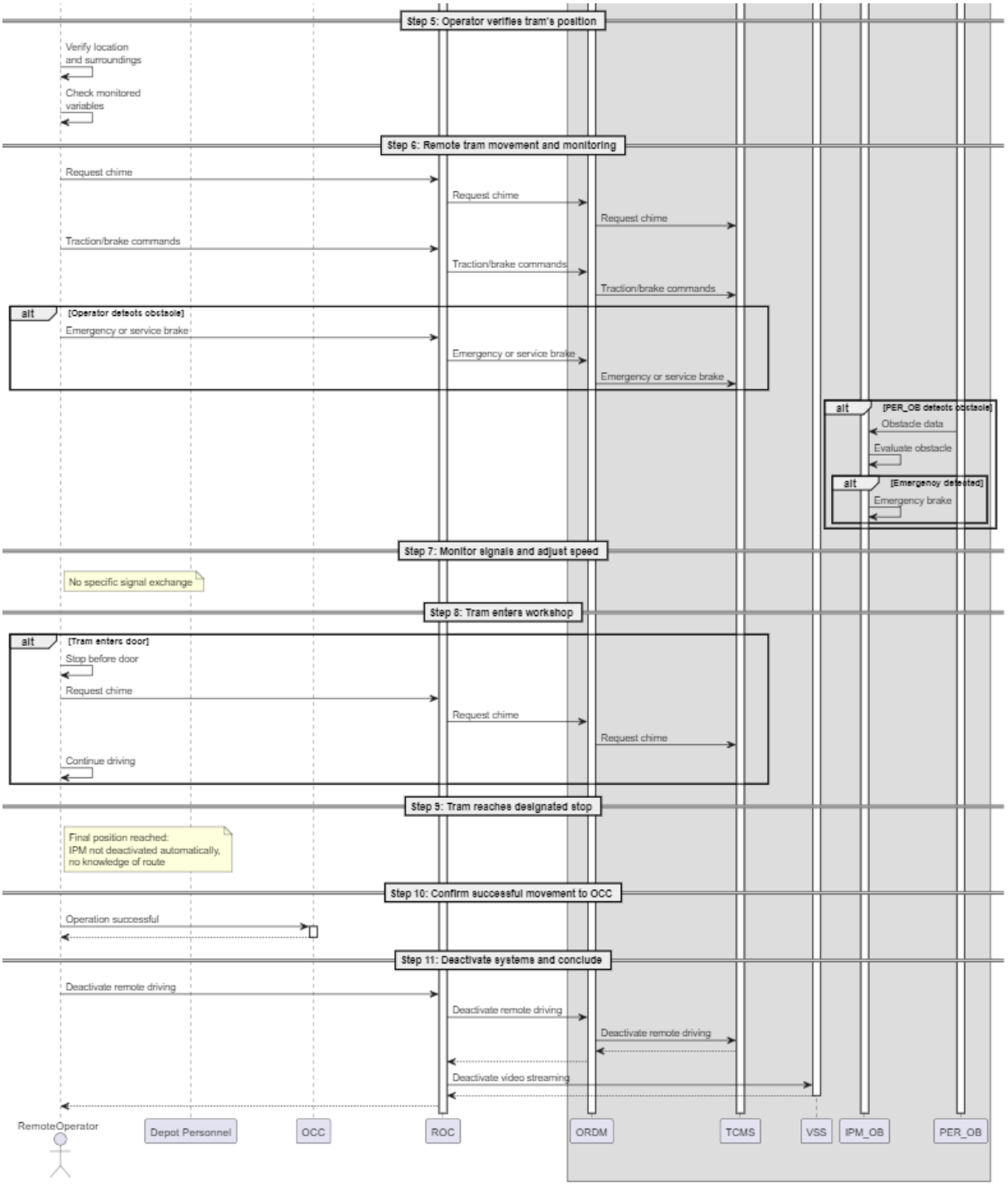
	on the tracks or in the yellow zone, and if it's safe, proceeds inside.
Step 8.1	*If the operator notices an object on the tracks that prevents the completion of the route, they must initiate braking or emergency braking, depending on the situation. If the remote operator does not perform this procedure, the system initiates automatic emergency braking. After the obstacle is removed, the remote operator must repeat Step 8.*
Step 9	*The tram reaches its designated track and spot (Track B), and the remote operator stops it at the designated position using deceleration. The system monitors maximum shunting speed.*
Step 9.1	*If the obstacle is not noticed by the remote driver, and they didn't stop in timely manner, the system initiates emergency braking.*
Step 10	*The remote operator sends a confirmation signal to the OCC, indicating the successful completion of the movement. The signal must be confirmed by OCC.*
Step 11	*The remote operator deactivates the sensors, cameras, and communication systems. A communication confirmation is exchanged between the remote operator and the tram to acknowledge the completion of the remote parking process. The process concludes with all systems properly switched off, and communication is concluded.*
Step X	*If, at any point during the process, an unsuccessful communication confirmation or safety violation is detected, the process will branch to the common outcome labelled as 'X.' Outcome 'X' signifies that the operation cannot proceed successfully, and appropriate actions, such as reporting the issue to the OCC and halting the operation, will be taken.*
Postcondition	*The tram is parked in the designated position.* *All communication and systems are deactivated.*
Use case notes	*This use case outlines the procedures and rules for safely remotely parking a tram within a depot, ensuring compliance with safety and operational guidelines.*

	This Use Case has the following links with the operational rules (D5.6 Annex 2): • *OR.00.01 Communication with OCC* • *OR.00.02 End of communication with OCC* • *OR.00.05 Reporting defects and faults* • *OR.01.02 Vigilance device (Deadman function) activation/deactivation* • *OR.02.02 Tram movements in depots and workshops* • *OR.02.03 Driver check list before moving inside or outside the workshop* • *OR.02.04 Actions to do if power is off before entering or leaving the workshop* • *OR.02.05 How to enter/exit workshop after driver checklist* • *OR.02.06 Controlling motorized points within depots* • *OR.02.07 Track obstacles check before driving* • *OR.03.01 Recognising signals* • *OR.03.02 Recognising signs* • *OR.03.05 Tram cab key control modes* • *OR.03.07 Speed limits* • *OR.03.09 Turning trams in depots* • *OR.03.12 Check proper visibility* • *OR.03.13 Acoustic signal before driving* • *OR.03.14 Detect obstacle (object in the or near track)* • *OR.03.16 Event of unintended tram separation* • *OR.03.17 Braking in the event of derailment*

Table 7: Use case “Remote parking in a depot” description

Sequence Diagram for Remote parking in a depot




Step 5: Operator verifies tram's position
Verify location and surroundings
Check monitored variables
Step 6: Remote tram movement and monitoring
Request chime
Request chime
Request chime
Traction/brake commands
Traction/brake commands
Traction/brake commands
alt
[Operator detects obstacle]
Emergency or service brake
Emergency or service brake
Emergency or service brake
alt
[PER_OB detects obstacle]
Obstacle data
Evaluate obstacle
alt
[Emergency detected]
Emergency brake
Step 7: Monitor signals and adjust speed
No specific signal exchange
Step 8: Tram enters workshop
alt
[Tram enters door]
Stop before door
Request chime
Request chime
Request chime
Continue driving
Step 9: Tram reaches designated stop
Final position reached:
IPM not deactivated automatically,
no knowledge of route
Step 10: Confirm successful movement to OCC
Operation successful
Step 11: Deactivate systems and conclude
Deactivate remote driving
Deactivate remote driving
Deactivate remote driving
Deactivate video streaming
RemoteOperator
Depot Personnel
OCC
ROC
ORDM
TCMS
VSS
IPM_OB
PER_OB

Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Remote parking in a depot (UC.5.6.5.24)	**Tram preparation** • Check-out/Check-in vehicle • Request tram wake-up • Supervise tram wake-up • Manage Tram Preparation Staff request • Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction • Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream • Remove stop shoes • Manage appropriate and safe conditions • Manage Remote Driver request • Request tram hold • Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage windscreen cleaning • Manage exterior lighting • Manage the bell • Manage trams modes **Monitor Tram conditions** • Supervise trams • Monitor fire alarm • Monitor pantograph

	• Monitor battery protection mode • Measure tram's speed • Provide UTC time • Monitor trams • Transmit periodically tram's location **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track **Tram movement** • Drive tram remotely • Perform shunting • Provide Brake Command for Parking Braking • Provide acceleration • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Acquire realised braking effort • Detect sliding • Provide Brake Command for Emergency Braking • Apply and release braking forces • Check ad hoc brake release • Process remote driving commands • Monitor speed and distance • Command Emergency Brake • Transmit Emergency Stop • Determine maximum authorised speed • Supervise runaway movement **Events management** • Assist troubleshooting

Table 8: Logical functions needed for UC.5.6.5.24 (Automatized function in green, Remote functions in orange and Manual functions in tram unit in red)

Operational use case for Remote washing

Table 9 summarizes the operation use case for remote washing and it was defined in R2DATO Task 5.6 [1].

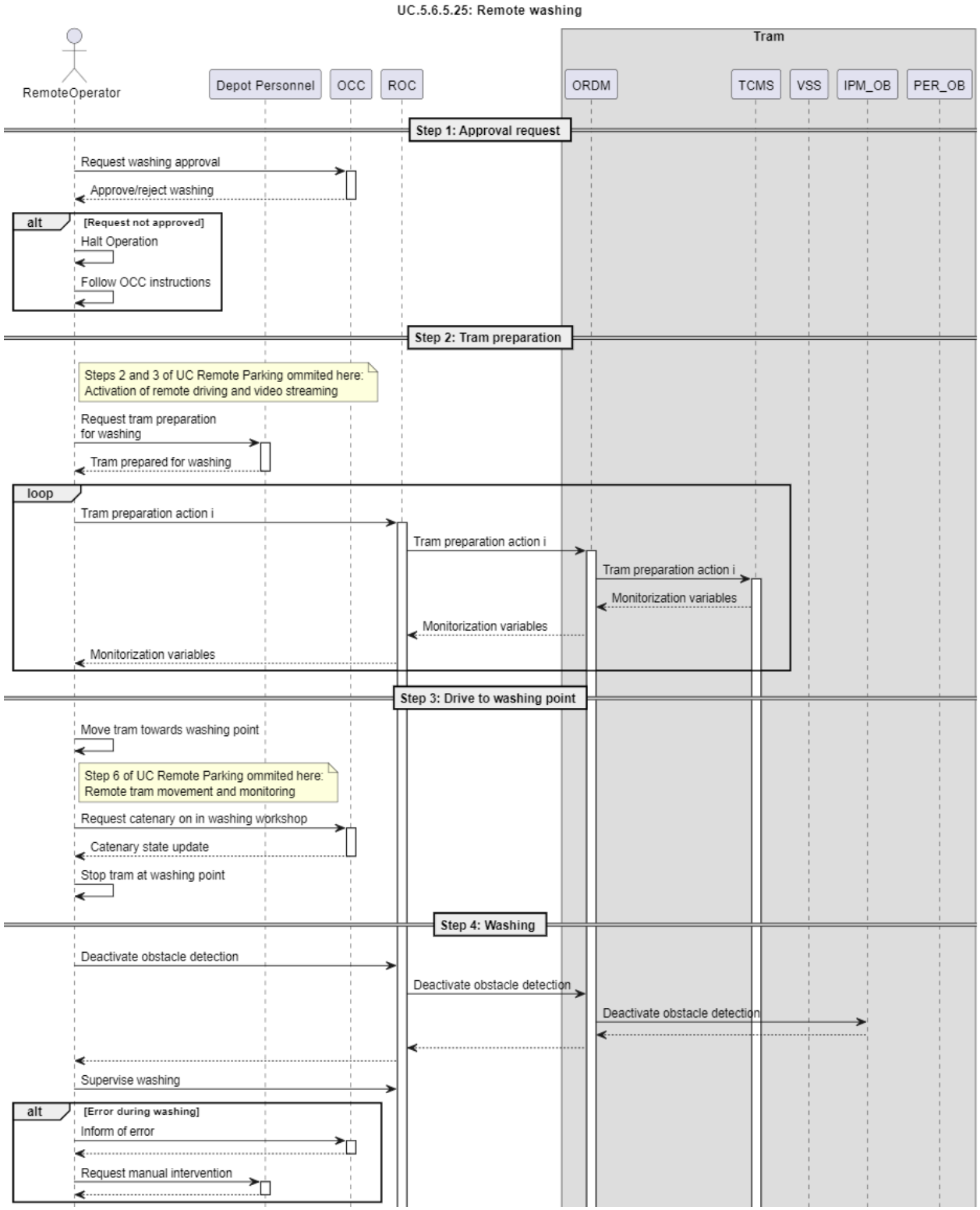
Use case field	Description	
ID	UC.5.6.*5.25*	
Use case name	*Remote washing*	
Main actor	*Tram remote driver-operator (remote operator)*	
Other actors	• *Control centre operator or operations management room (at the depot) – OCC* • *Depot personnel*	
Use case summary	*The remote tram washing process allows a tram to be washed remotely with approval and instructions from the OCC. The process involves establishing a connection with the tram, obtaining approval for washing, receiving pre-wash instructions from the OCC, performing manual actions on the tram, such as closing windows and hatches, moving to the washing point, undergoing the washing process, using chimes (or bells) for visibility upon exit, and receiving post-wash instructions from the OCC. If the tram stops during the process, the wash stops automatically and requires reset by the OCC.*	
Applicability	• *Geographical: European level (national level, which countries? / European level)* • *Operational category: Urban*	
Main goal	*The main goal of this use case is to facilitate the automated remote washing of trams while adhering to specific pre- and post-wash instructions, ensuring the safety and cleanliness of the tram.*	
Preconditions	• *Communication between the remote operator and the tram is established.* • *Pre-wash instructions (operational rules) from the network operator are known.*	
Termination outcome	**Successful outcomes**	• *The tram completes the washing process.* • *Post-wash instructions are received and followed.*
	Unsuccessful outcomes	• *The tram stops during the washing process.* • *Pre-wash instructions are not received by the OCC.* • *Post-wash instructions are not received or followed.*
Condition affecting termination outcome	**Outcome 2**	*Where relevant, if the tram or a washing equipment stops during the washing process, manual intervention*

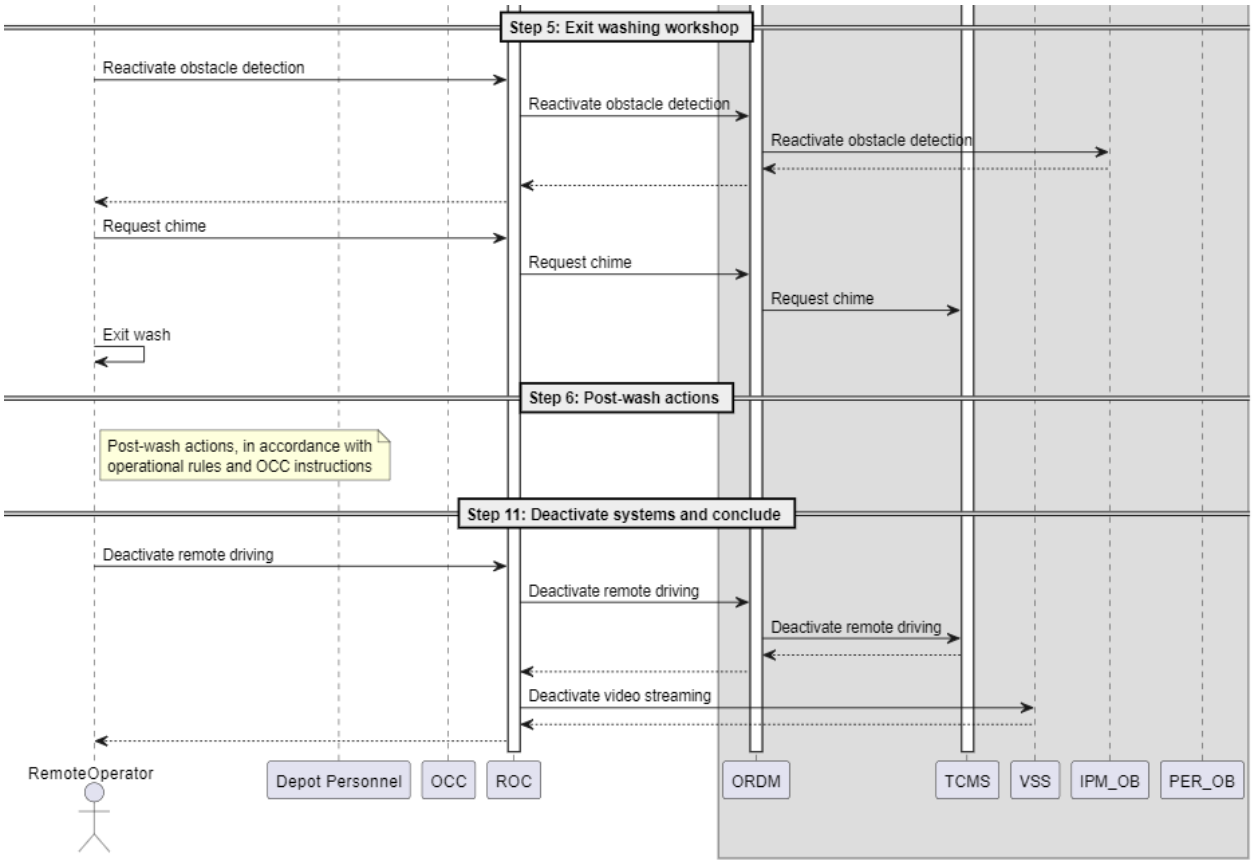
		is required, and the wash process stops automatically until reset by the OCC.
Use case scenario	**Step 1**	*The remote operator contacts OCC to request washing approval, which is subsequently granted.*
	Step 1.1	*If the request is not approved, the procedure must be halted, and instructions from the OCC must be followed.*
	Step 2	*The remote operator, with assistance from depot personnel, prepares the tram for the washing procedure according to the network's operational rules. Some actions, such as closing windows and hatches, are manually performed on the tram by depot personnel.*
	Step 3	*After receiving approval and completing necessary preparations, the remote operator remotely moves to the washing point at shunting speed.*
	Step 4	*Before entering the washing workshop, where a green light indicates that the overhead catenary system is off or blank, the remote operator stops the tram and contacts OCC to turn on the overhead catenary system.*
	Step 5	*The tram undergoes the washing process until it is complete.*
	Step 5.1	*If the washing process is not completed, the OCC must be contacted, and manual intervention is required.*
	Step 6	*The emergency lights are activated automatically when the tram is in remote driving mode (for all relevant use cases, all the time while the tram remote connection is turned on). After using chimes (or bells) remotely, the remote operator exits the wash.*
	Step 7	*The remote operator carries out post-wash instructions in accordance with the network's operational rules and instructions from the OCC, such as parking in a specific spot.*
	Step 8	*The remote operator performs the disconnection and switches off the remote driving mode.*
	Step X	*If an unsuccessful communication confirmation or safety violation is detected at any point during the*

		process, the operation will branch to the common outcome labelled as "X." Outcome "X" signifies that the operation cannot proceed successfully, and appropriate actions, such as reporting the issue to the OCC and halting the operation, will be taken. *Safety precautions are based on three pillars:* • *Speed detection and regulation.* • *Obstacle detection and decision-making.* • *Leaving the remote-driving zone.*
Postcondition	*The tram has completed the washing process.* *All post-wash instructions have been followed.*	
Use case notes	*This process outlines the procedures and rules for remotely washing trams, including communication, manual actions, and compliance with pre- and post-wash instructions, while ensuring safety and cleanliness.* *The operational rules linked to the use case are (D5.6 Annex 2):* • *OR.00.01 Communication with OCC* • *OR.00.02 End of communication with OCC* • *OR.00.05 Reporting defects and faults* • *OR.01.02 Vigilance device (Deadman function) activation/ deactivation* • *OR.02.02 Tram movements in depots and workshops* • *OR.02.03 Driver check list before moving inside or outside the workshop* • *OR.02.04 Actions to do if power is off before entering or leaving the workshop* • *OR.02.05 How to enter/exit workshop after driver checklist* • *OR.02.06 Controlling motorized points within depots* • *OR.02.07 Track obstacles check before driving* • *OR.03.01 Recognising signals* • *OR.03.02 Recognising signs* • *OR.03.03 Speed principle* • *OR.03.05 Tram cab key control modes* • *OR.03.07 Speed limits* • *OR.03.10 Washing procedure* • *OR.03.12 Check proper visibility* • *OR.03.13 Acoustic signal before driving* • *OR.03.14 Detect obstacle (object in the or near track)* • *OR.03.17 Braking in the event of derailment*	

Table 9: Use case “Remote washing” description

Sequence Diagram for Remote washing





Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Remote washing (UC.5.6.5.25)	**Tram preparation** • Check-out/Check-in vehicle • Request tram wake-up • Supervise tram wake-up • Manage Tram Preparation Staff request • Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction • Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream

	• Remove stop shoes • Manage appropriate and safe conditions • Manage Remote Driver request • Request tram hold • Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage tram modes • Manage exterior lighting • Manage the bell • Inhibit sanding • Manage windscreen cleaning **Monitor Tram conditions** • Supervise trams • Monitor fire alarm • Monitor pantograph • Monitor battery protection mode • Measure tram's speed • Provide UTC time • Monitor trams • Transmit periodically tram's location **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track **Tram movement**

	• Drive tram remotely • Perform shunting • Provide Brake Command for Parking Braking • Provide acceleration • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Acquire realised braking effort • Detect sliding • Provide Brake Command for Emergency Braking • Apply and release braking forces • Check ad hoc brake release • Process remote driving commands • Monitor speed and distance • Command Emergency Brake • Transmit Emergency Stop • Determine maximum authorised speed • Supervise runaway movement **Events management** • Assist troubleshooting

Table 10: Logical functions needed for UC.5.6.5.25 (Automatized function in green, Remote functions in orange and Manual functions in tram unit in red)

Operational use case for Pre-departure tram check

Table 11 summarizes the operation use case for pre-departure tram check and it was defined in R2DATO Task 5.6 [1].

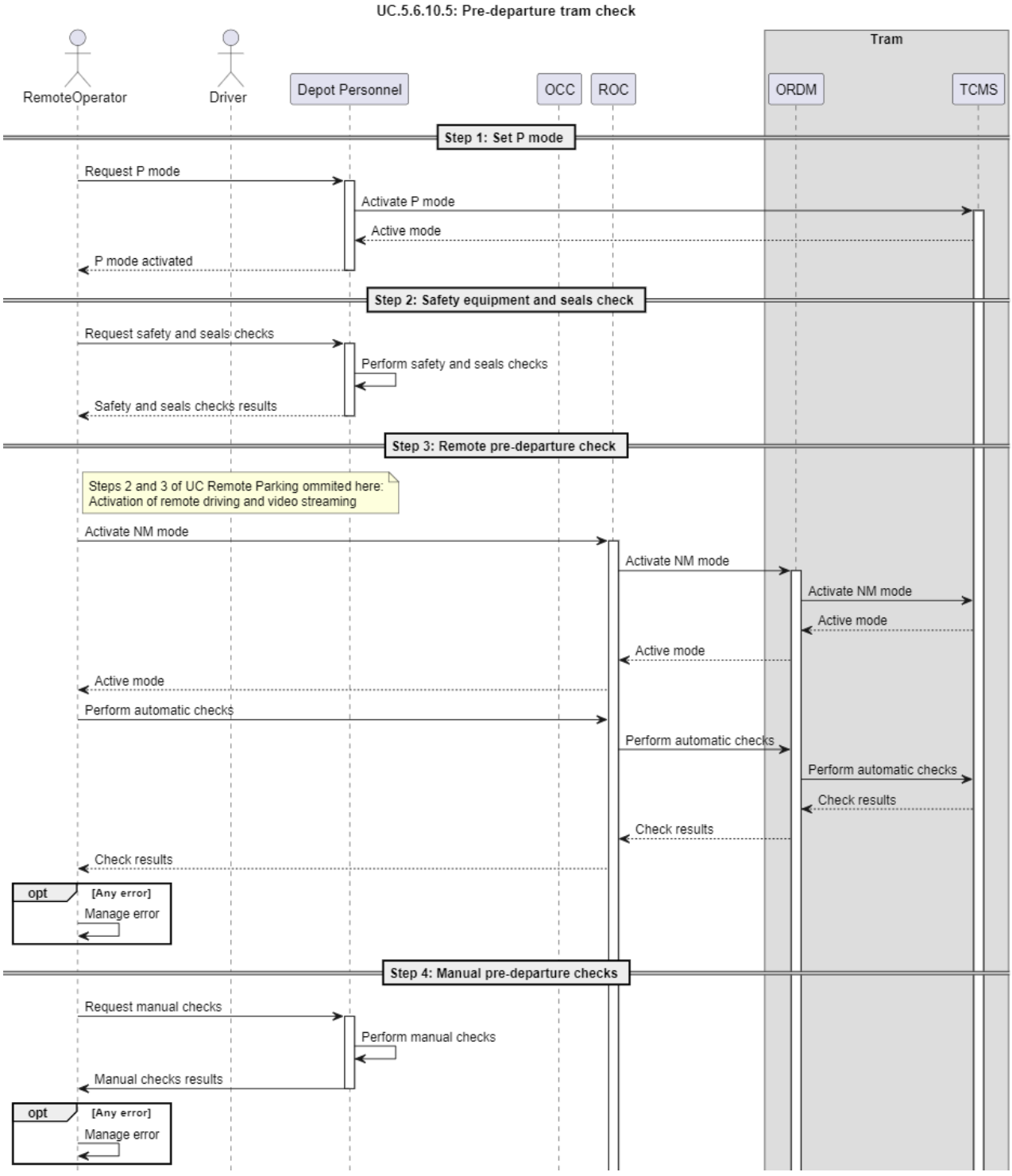
Use case field	Description	
ID	UC.5.6.10.5	
Use case name	*Pre-departure tram check*	
Main actor	*Tram remote driver-operator (remote operator)*	
Other actors	• *Control centre operator or operations management room (at the depot) (OCC)* • *Supervising system* • *Depot personnel* • *Tram driver* • *Traffic manager*	
Use case summary	*The "Pre-departure tram check" use case involves preparing a tram for departure by following a checklist defined by the network operator. It includes verifying safety equipment, manual checks by personnel, and self-checks of various tram systems. The goal is to ensure that the tram is in a safe and operational condition before departure.*	
Applicability	• *Geographical: Europe* • *Operational category: Urban*	
Main goal	*The main goal of this use case is to ensure that a tram is in a safe and operational condition before departing on its route. This includes verifying safety equipment, conducting manual checks, and performing self-checks of tram systems.*	
Preconditions	• *The tram is in a state ready for pre-departure checks in remote (telecommand) mode.* • *Communication between the tram and remote is established.*	
Termination outcome	**Successful outcomes**	*The tram successfully passes all pre-departure check and ready for the shift approaches the end of the depot area/beginning of traffic area*
	Unsuccessful outcomes	• *The tram fails any of the pre-departure checks and unable to proceed for operation.* • *Communication between the tram and remote operator is disrupted.*
Condition affecting termination outcome	**Outcome 2**	*If the tram fails any of the pre-departure checks, further action may be required to rectify the issues before departure, or the tram must be substituted.*

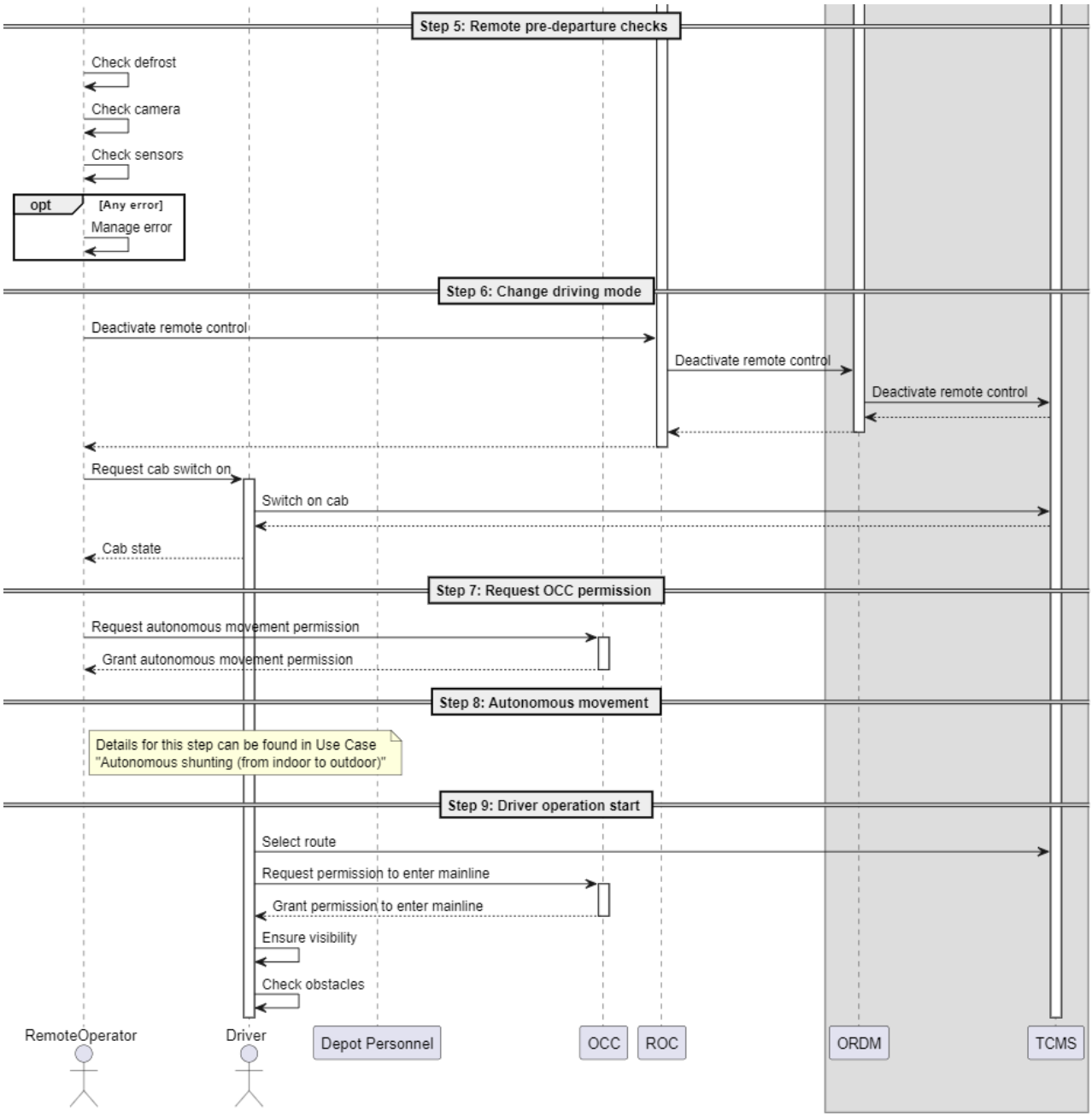
Use case scenario	**Step 1**	*Set the tram to "P" mode to prepare for the pre-departure checks.*
	Step 2	*Safety Equipment and Seals Check.* *The depot personnel must verify that all safety equipment and seals are present.*
	Step 3	*Remote pre-departure check* • *Remotely switch to "NM" mode and follow the pre-departure checklist defined by the network operator.* • *Automatically perform checks on various tram systems: external lights, chimes & horns, interior lights, wipers & washer, passenger announcement system, doors open and close, safety brake, track brake, console indicator lamps, traction, mirror cameras, pantograph status, and control of alarms on TCMS-HMI monitors or alarm lamps on driver desk.*
	Step 3.1	*If any system of the tram doesn't work properly then this information is sent immediately to remote operator to take an action.*
	Step 4	*Manual pre-departure check* *Depot personnel conducts manual checks on all safety equipment and seals being present, saloon (visual check, i.e., floor is clean, dry and clear of any obstructions, emergency handle covers in place, overhead panels are secure, and inspect widows for defects, seal on the first aid kit box, seal on fire extinguisher, if switch iron for manual operation of the switches is on place, inside of the vehicle for graffiti and damages), outside of the vehicle for graffiti and damages.*
	Step 5	*Pre-movement checks* *Before every movement, the remote operator must ensure the visibility: check defrost function, camera views, and sensors.*
	Step 6	*Change the driving mode.* *After the remote pre-departure check is completed, the remote operator must conclude remote control session. The tram driver must turn on the tram cab locally from the tram.*

Step 6	*Contact OCC to request permission to proceed to the depot gate.* *The tram driver contacts OCC and request permission to proceed to the depot gate.*
Step 7	*Autonomous movements at the depot gate.* *After the request is approved, the tram autonomously proceeds to the depot gate at shunting speed and stops. The ATO system continuously monitors static and dynamic obstacles.*
Step 7.1	*The obstacle is detected, and the tram stops.*
Step 8	*The tram driver selects the route and contacts the traffic manager to request permission to enter the mainline. They must input the RTS before joining the mainline and always comply with OCC tram movement instructions. Before making any movements, they must ensure proper visibility and visually check the track for any obstacles.*
Step X	*If an unsuccessful communication confirmation or safety violation is detected at any point during the process, the operation will branch to the common outcome labelled as "X."* *Outcome "X" signifies that the operation cannot proceed successfully, and appropriate actions, such as reporting the issue to the OCC and halting the operation, will be taken.*
Postcondition	*The tram is deemed safe and operationally ready for departure if all pre-departure checks are successfully completed. OCC is ready to give a green line to leave for traffic area.*
Use case notes	*This Use Case has the following links with the operational rules (D5.6 Annex 2):* - *OR.00.01 Communication with OCC* - *OR.00.05 Reporting defects and faults* - *OR.01.01 Driver check list before a trip* - *OR.02.01 After pre-departure check readiness* - *OR.02.06 Controlling motorized points within depots* - *OR.02.07 Track obstacles check before driving* - *OR.03.01 Recognising signals* - *OR.03.02 Recognising signs* - *OR.03.05 Tram cab key control modes* - *OR.03.12 Check proper visibility* - *OR.03.13 Acoustic signal before driving*

Table 11: Use case “Pre-departure tram check” description

Sequence Diagram for Pre-departure tram check





Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Pre-departure tram check (UC.5.6.10.5)	**Tram preparation** • Check-out/Check-in vehicle • Remove stop shoes • Request tram hold • Manage appropriate and safe conditions

	• Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction • Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream • Define mission • Set routes • Dispatch orders • Determine ATO state • Register autonomous tram unit • Provide vehicle database • Be identified like an autonomous tram • Determine/verify and transmit JP data • Determine/verify and transmit MP data • Determine mission data • Manage mission execution • Trigger events • Receive anomalies in task or mission execution • Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage climatization • Manage windscreen cleaning • Manage exterior lighting • Manage the bell • Manage tram modes • Manage cab control **Monitor Tram conditions**

	• Manage reporting • Supervise trams • Monitor fire alarm • Monitor tram unit failures • Monitor pantograph • Monitor battery protection mode • Measure tram's speed • Provide UTC time • Receive status report • Monitor trams • Transmit driving anomalies • Transmit periodically tram's location **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track **Tram movement** • Manage journey • Perform shunting • Provide acceleration • Provide Brake Command for Parking Braking • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Provide Brake Command for Emergency Braking • Acquire realised braking effort • Detect sliding • Apply and release braking forces • Check ad hoc brake release

	• Stop exactly at the intended location • Respect JP Timing Points and Optimize the consumption • Control initial traction effort • Calculate expected traction effort • Determine maximum authorised speed • Regulate traction and braking effort • Detect that final stopping point has been reached • Change running direction • Manage communication exchanges with driver • Monitor speed and distance • Supervise runaway movement • Transmit supervision orders • Transmit Emergency Stop • Manage stopping points and passing points • Command Emergency Brake **Events management** • Assist troubleshooting • Manage tram incidents

Table 12: Logical functions needed for UC.5.6.10.5 (Automatized function in green, Remote functions or partianlly automatized in orange and Manual functions in tram unit in red)

FUNCTIONAL USE CASE FOR AUTONOMOUS SHUNTING (FROM INDOOR TO OUTDOOR)

Operational use case for Autonomous shunting (from indoor to outdoor)

Table 13 summarizes the operation use case for Autonomous shunting and it was defined in R2DATO Task 5.6 [1].

Use case field	Description	
ID	UC.5.6.2.3.1	
Use case name	*Autonomous shunting (from indoor to outdoor)*	
Main actor	• *Autonomous tram* • *Tram remote driver-operator (remote operator)*	
Other actors	• *Control centre operator or operations management room (at the depot) (OCC)* • *Depot personnel*	
Use case summary	*This use case involves the autonomous shunting of a tram, allowing it to move between parking spaces without the presence of a driver. The tram transitions from a sheltered indoor area to an outdoor environment. Before initiating movement, the tram conducts a pre-movement self-check. The route is established by a remote operator, and the tram verifies its position and confirms movement with the OCC. The OCC ensures that motorized points are correctly aligned, and the tram checks that the track is clear for movement. Once outside, it adapts its speed and driving style based on environmental conditions and encountered obstacles.*	
Applicability	• *Geographical: Europe* • *Operational category: Urban*	
Main goal	*The main goal of this use case is to autonomously shunt a tram from an indoor parking space to an outdoor location while ensuring safety and adaptability to changing environmental conditions.*	
Preconditions	• *The tram is in a state ready for autonomous shunting.* • *Communication between the remote operator and the tram is established.*	
Termination outcome	**Successful outcomes**	• *The tram successfully completes the shunting process from indoor to outdoor.*
	Unsuccessful outcomes	• *The tram encounters obstacles or adverse environmental conditions that require intervention.* • *Communication between remote operator and the tram or with the OCC is lost.*
Condition affecting termination outcome	**Outcome 2**	*If the tram encounters obstacles or adverse environmental conditions, it must take appropriate*

		actions as per the operational rules and instructions from the OCC.

Use case scenario	**Step 1**	*Pre-Movement Self-Check*
		
		The remote operator initiates a self-check remotely to ensure the tram is in a suitable operational condition. Additionally, the following checks must be performed:
		
		• *Through perception system:*
		  ○ *Verify power is on and red light is illuminated*
		  ○ *Confirm that there is no crane obstructing the tram's path*
		  ○ *Check for any tags indicating that the tram cannot be moved*
		  ○ *Ensure no person is working on or near the tram*
		  ○ *Tram is not coupled to another tram*
		• *Conducted by depot personnel*
		  ○ *Verify the absence of scotches (stop shoes) under the wheels*
		  ○ *Ensure that body catchers are raised*
		  ○ *Confirm that all panels are securely fastened.*

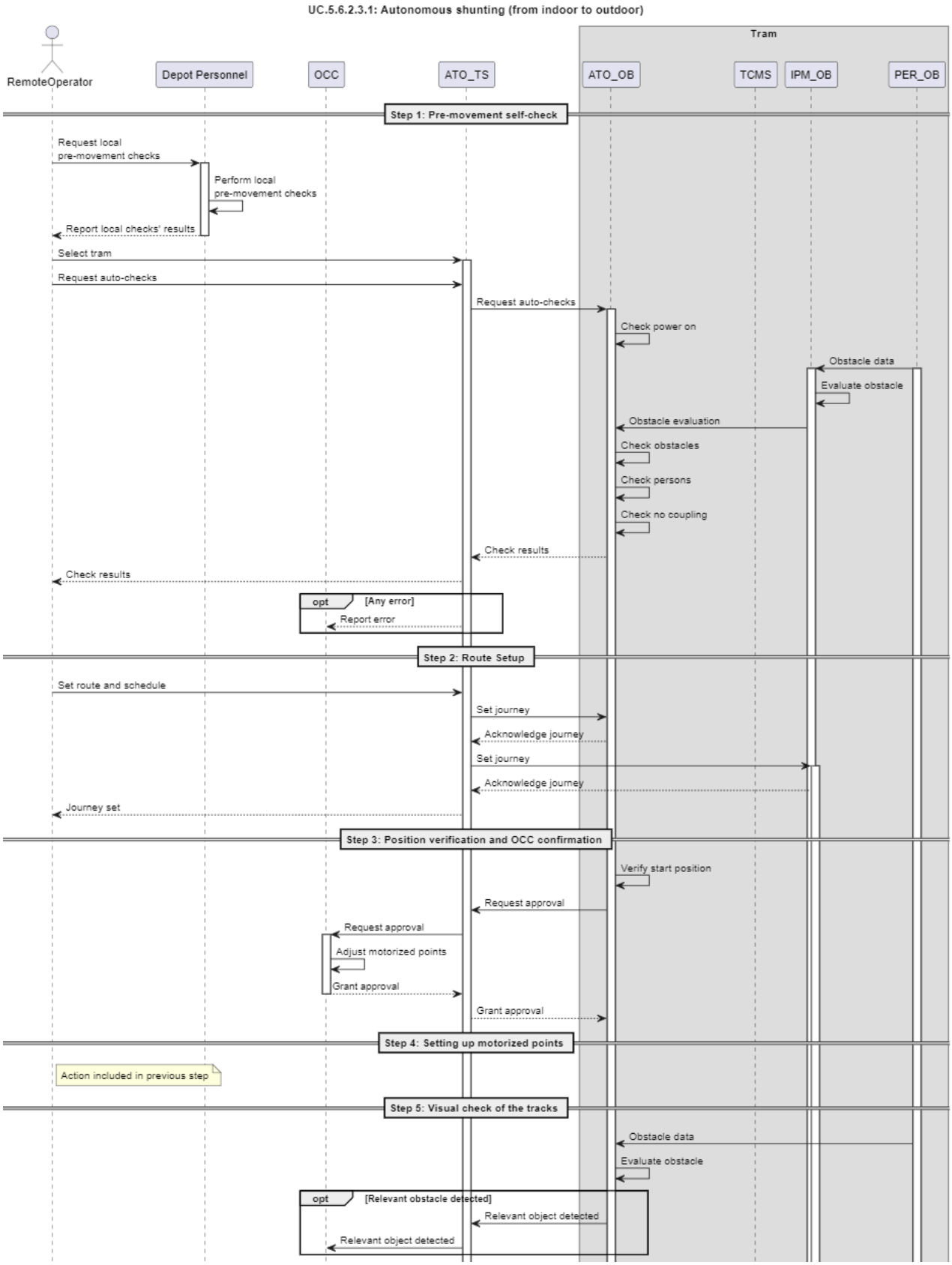
	Step 1.1	*If any failures are identified during this stage, the tram must transmit this information to both the remote operator and the OCC.* *Additionally, if the Overhead Catenary System is off, a request to the OCC must be transmitted.*
	Step 2	*Route Setup* *After successful self-check, a remote operator sets up the route from A to B.*
	Step 3	*Position Verification and OCC Confirmation* *The tram verifies its position and requests approval from the OCC. OCC must approve the request.*
	Step 4	*Setting up motorized points* *The OCC adjusts motorized points according to the tram route.*
	Step 5	*Visual check of the tracks* *The tram verifies that the track is clear for movement.*
	Step 5.1	*If there is an obstacle on the track, the tram must evaluate how dangerous the object is (e.g., whether it is newspaper or a person) and then make a decision:*

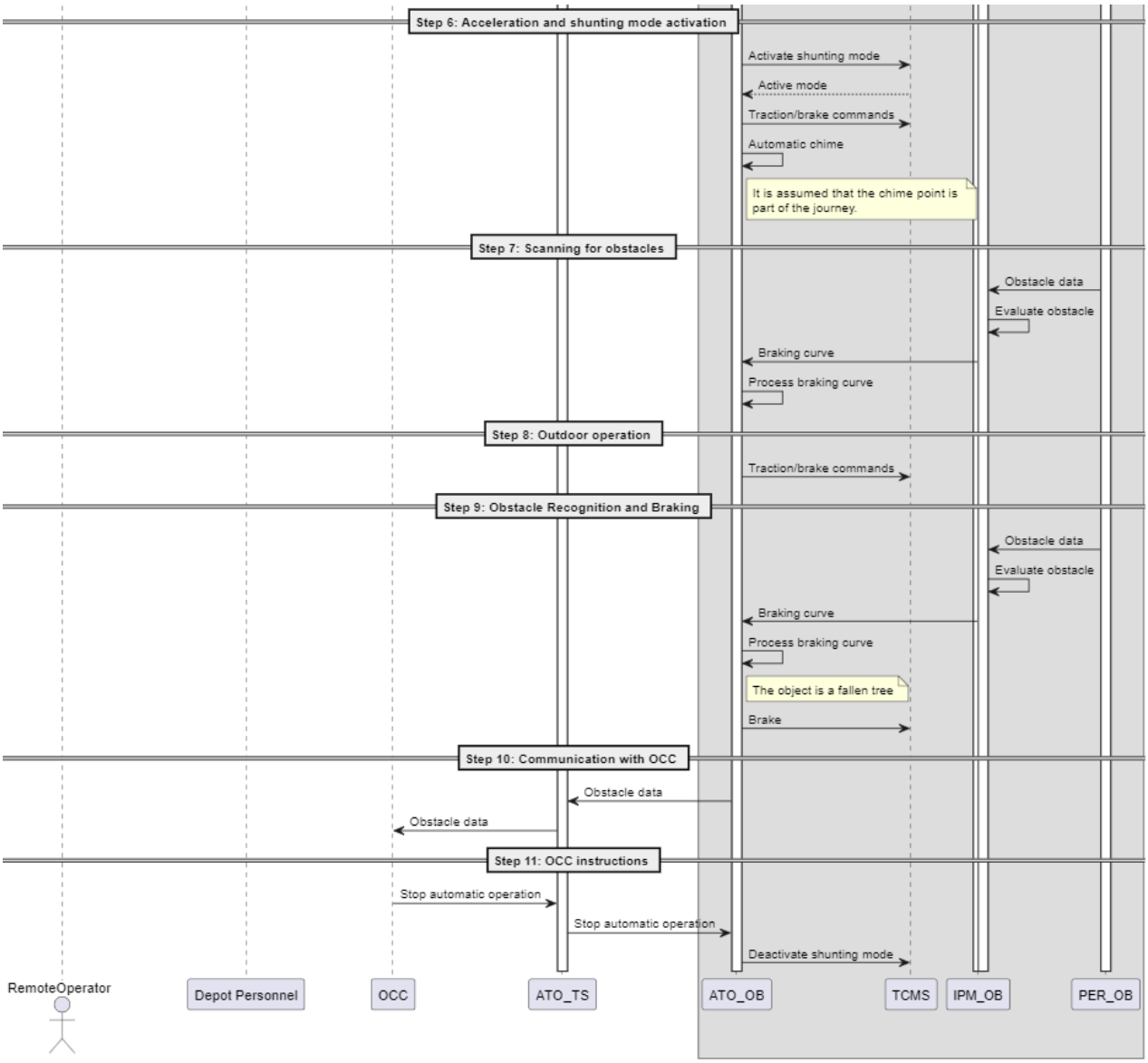
	proceed or follow the instructions (e.g., use chimes or stop and communicate to the OCC).
Step 6	*Acceleration and Shunting Mode Activation* *The tram turns shunting mode and starts accelerating and approaches the shelter's gate. It chimes to indicate its intention to move through the gate.*
Step 7	*Scanning for Obstacles* *The tram scans its surroundings for obstacles and assesses safety.*
Step 8	*Outdoor Operation* *The tram continues moving outside, adjusting its speed, and driving style based on factors such as curves, junctions, time of day, weather conditions, and reflexes in the surroundings.*
Step 9	*Obstacle Recognition and Braking* *The tram encounters a fallen tree on the tracks. It recognises the obstacle and initiates braking.*
Step 10	*Communication with OCC* *Information about the obstacle is sent to the OCC.*
Step 11	*OCC instructions* *The OCC gives instructions to the tram to stop and wait for personnel to remove the tree.*
Step 12	*After driving is restored, the tram proceeds to the final destination. The supervising systems that ensure tram safety are automatically deactivated after the tram comes to a halt.*
Step 12.1	*If a tram deviates from the route and exits the autonomous-operation area, the system initiates braking to stop the tram. The remote operator is then notified of the issue, and OCC is contacted.*
Postcondition	*The tram successfully completes its autonomous shunting from indoor to outdoor.* *If an obstacle is encountered, the tram follows OCC instructions and stops, ensuring safety until the obstacle is cleared.*

Use case notes	*This use case outlines the procedures and rules for autonomously shunting a tram, considering various environmental factors, and ensuring safety throughout the process.* *This Use Case has the following links with the operational rules (D5.6 Annex 2):* - *OR.00.01 Communication with OCC* - *OR.00.02 End of communication with OCC* - *OR.00.05 Reporting defects and faults* - *OR.02.01 After pre-departure check readiness* - *OR.02.02 Tram movements in depots and workshops* - *OR.02.03 Driver check list before moving inside or outside the workshop* - *OR.02.04 Actions to do if power is off before entering or leaving the workshop* - *OR.02.05 How to enter/exit workshop after driver checklist* - *OR.02.06 Controlling motorized points within depots* - *OR.02.07 Track obstacles check before driving* - *OR.03.01 Recognising signals* - *OR.03.02 Recognising signs* - *OR.03.03 Speed principle* - *OR.03.05 Tram cab key control modes* - *OR.03.06 Factors affecting accelerating or braking capacity* - *OR.03.08 Driving technique on slippery track* - *OR.03.12 Check proper visibility* - *OR.03.13 Acoustic signal before driving* - *OR.03.14 Detect obstacle (object in the or near track)*

Table 13: Use case “Autonomous shunting (from indoor to outdoor)” description

Sequence Diagram for Autonomous shunting (from indoor to outdoor)





Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Autonomous shunting (from indoor to outdoor) (UC.5.6.2.3.1)	**Tram preparation** • Check-out/Check-in vehicle • Remove stop shoes • Request tram hold • Manage appropriate and safe conditions • Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction

	• Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream • Define mission • Set routes • Dispatch orders • Determine ATO state • Register autonomous tram unit • Provide vehicle database • Be identified like an autonomous tram • Determine/verify and transmit JP data • Determine/verify and transmit MP data • Determine mission data • Manage mission execution • Trigger events • Receive anomalies in task or mission execution • Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage climatization • Manage windscreen cleaning • Manage exterior lighting • Manage the bell • Manage tram modes • Manage cab control **Monitor Tram conditions** • Manage reporting • Supervise trams • Monitor fire alarm

	• Monitor tram unit failures • Monitor pantograph • Monitor battery protection mode • Measure tram's speed • Provide UTC time • Receive status report • Monitor trams • Transmit driving anomalies • Transmit periodically tram's location **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track **Tram movement** • Manage journey • Perform shunting • Provide acceleration • Provide Brake Command for Parking Braking • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Provide Brake Command for Emergency Braking • Acquire realised braking effort • Detect sliding • Apply and release braking forces • Check ad hoc brake release • Stop exactly at the intended location • Respect JP Timing Points and Optimize the consumption • Control initial traction effort

	• Calculate expected traction effort • Determine maximum authorised speed • Regulate traction and braking effort • Detect that final stopping point has been reached • Change running direction • Manage communication exchanges with driver • Monitor speed and distance • Supervise runaway movement • Transmit supervision orders • Transmit Emergency Stop • Manage stopping points and passing points • Command Emergency Brake **Events management** • Assist troubleshooting • Manage tram incidents

Table 14: Logical functions needed for UC.5.6.2.3.1 (Automatized function in green, Remote functions or partianlly automatized in orange and Manual functions in tram unit in red)

Operational use case for Autonomous shunting of several vehicles simultaneously using V2X

Table 15 summarizes the operation use case for Autonomous shunting of several vehicles simultaneously using V2X and it was defined in R2DATO Task 5.6 [1].

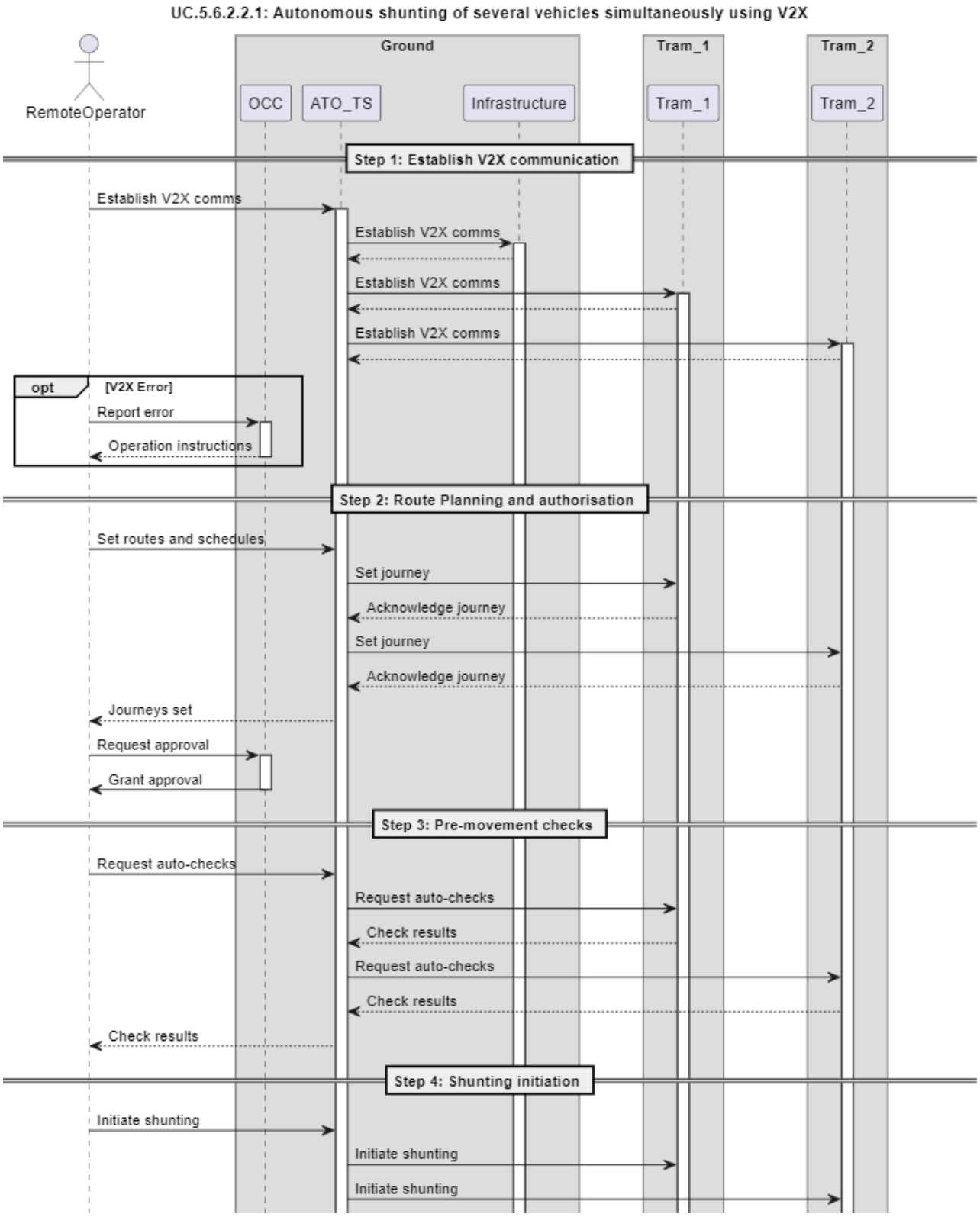
Use case field	Description	
ID	UC.5.6.2.2.1	
Use case name	*Autonomous shunting of several vehicles simultaneously using V2X*	
Main actor	• *Two autonomous trams* • *Tram remote driver-operator (remote operator)*	
Other actors	• *OCC (Operations Control Centre)* • *Infrastructure*	
Use case summary	*This use case encompasses the simultaneous autonomous shunting of multiple trams, a process designed to enhance operational efficiency, particularly in scenarios requiring tram substitutions, such as directing a malfunctioning tram to the maintenance workshop. To achieve this, V2X technology is used for precise coordination and control of the trams' movements.*	
Applicability	• *Geographical: Europe* • *Operational category: Urban*	
Main goal	*The primary objective of this use case is the simultaneous autonomous shunting of multiple trams, achieving efficiency and coordination through V2X communication. It's important to note that this use case does not rely on cameras for environmental analysis but instead leverages V2X communication to interact with infrastructure components and other vehicles, all operating within the V2X protocol. Additionally, the interconnected infrastructure facilitates automated management of signals and motorized points.*	
Preconditions	• *The trams are in a state ready for autonomous shunting.* • *Communication between the trams and remote operator is established.*	
Termination outcome	**Successful outcomes**	• *Two trams are successfully shunted simultaneously.* • *Communications between the trams, infrastructure and the remote operator are maintained.*
	Unsuccessful outcomes	• *Coordination issues among multiple trams result in conflicts or collisions.* • *Communication with OCC, remote operator or with infrastructure is lost.*

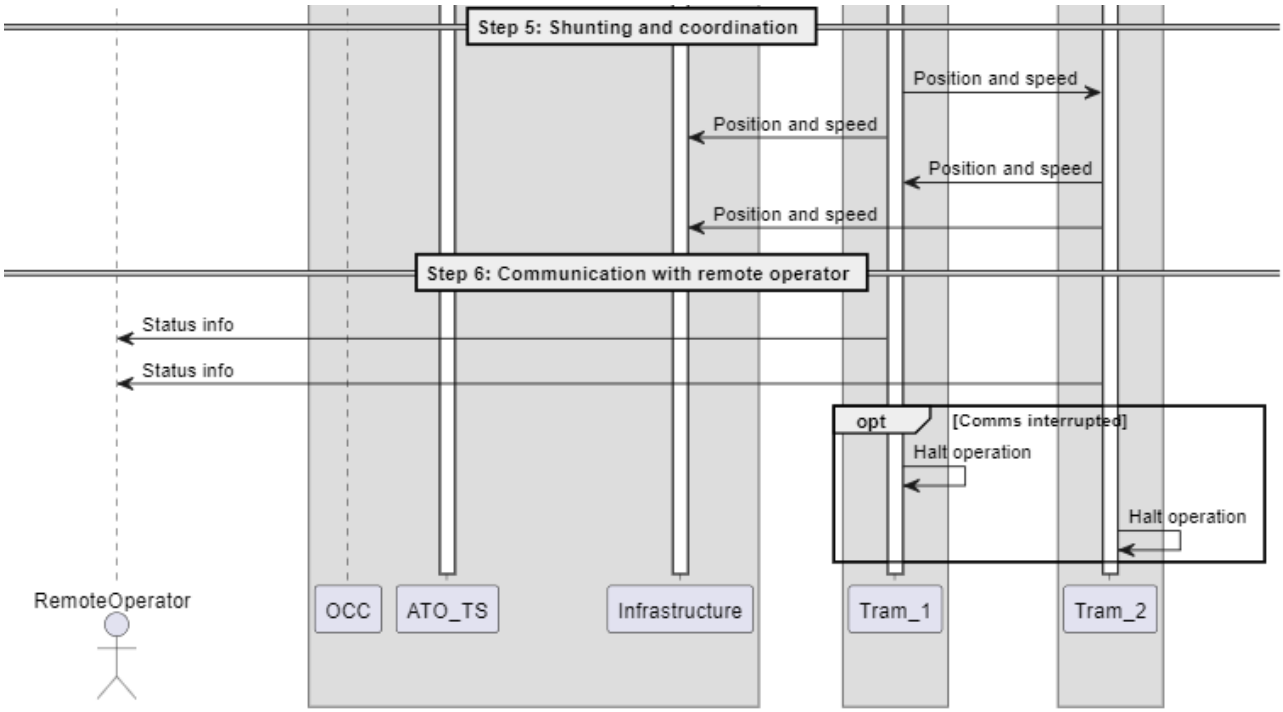
Condition affecting termination outcome	**Outcome 2**	*If coordination issues or conflicts arise among multiple trams, they must follow protocols to resolve the situation. The OCC must be notified.* *If the communication with any of the actors is disrupted, the systems must be relaunched and try to reconnect following the network's protocols.*
Use case scenario	**Step 1**	*Remote operator establishes V2X communication between the trams and with the infrastructure and verifies that communication works properly.*
	Step 1.1	*If connection fails to set up, the remote operator must repeat an attempt, following the network's manual. In case of unsuccessful attempts, the remote operator must contact the OCC for the instructions.*
	Step 2	*Route Planning and authorisation* *The remote operator set up the routes for the trams to shunt. The trams verify their positions and send confirmation to the remote operator. The remote operator contacts the OCC to confirm the shunting procedure. The OCC authorises the movement.*
	Step 2.1	*If the OCC doesn't respond, the remote operator must repeat an attempt, following the protocols.*
	Step 2.2	*In case of unsuccessful attempts, the shunting process must be terminated.*
	Step 3	*Pre-Movement Checks* *Both trams are required to perform pre-movement checks and communicate their readiness to the remote operator.*
	Step 3.1.	*In case of failures and other issues, remote operator must notify the OCC.*
	Step 4	*Shunting Initiation* *Remote operator initiates autonomous shunting.*
	Step 5	*Shunting and Coordination* *Trams autonomously shunt simultaneously, coordinating their movements. The trams also communicate with the infrastructure allowing the*

		motorised points to adjust according to the trams' routes.
	Step 6	*Communication with remote operator* *Trams maintain communication with the remote operator throughout the process to ensure control and safety.*
	Step 6.1	*In case of communication with the remote operator is disrupted or unavailable, the procedure must be immediately terminated, and the trams must halt.*
Postcondition	*Multiple trams are successfully shunted simultaneously using V2X communication.* *In the event of conflicts or collisions, trams follow protocols to ensure safety and resolve the situation.*	
Use case notes	*This use case outlines the procedures and potential unsuccessful scenarios for autonomously shunting multiple trams simultaneously, emphasising the importance of coordination and V2X communication.* *This Use Case has the following links with the operational rules (D5.6 Annex 2):* • *OR.00.01 Communication with OCC* • *OR.00.02 End of communication with OCC* • *OR.02.02 Tram movements in depots and workshops* • *OR.02.03 Driver check list before moving inside or outside the workshop* • *OR.02.04 Actions to do if power is off before entering or leaving the workshop* • *OR.02.05 How to enter/exit workshop after driver checklist* • *OR.02.07 Track obstacles check before driving* • *OR.03.01 Recognising signals* • *OR.03.02 Recognising signs* • *OR.03.12 Check proper visibility* • *OR.03.13 Acoustic signal before driving* • *OR.03.14 Detect obstacle (object in the or near track)*	

Table 15: Use case "Autonomous shunting of several vehicles simultaneously using V2X" description

Sequence Diagram for Autonomous shunting of several vehicles simultaneously using V2X


UC.5.6.2.2.1: Autonomous shunting of several vehicles simultaneously using V2X
RemoteOperator
Ground
OCC
ATO_TS
Infrastructure
Tram_1
Tram_1
Tram_2
Tram_2
Step 1: Establish V2X communication
Establish V2X comms
Establish V2X comms
Establish V2X comms
Establish V2X comms
opt
[V2X Error]
Report error
Operation instructions
Step 2: Route Planning and authorisation
Set routes and schedules
Set journey
Acknowledge journey
Set journey
Acknowledge journey
Journeys set
Request approval
Grant approval
Step 3: Pre-movement checks
Request auto-checks
Request auto-checks
Check results
Request auto-checks
Check results
Check results
Step 4: Shunting initiation
Initiate shunting
Initiate shunting
Initiate shunting



Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Autonomous shunting of several vehicles simultaneously using V2X (UC.5.6.2.2.1)	**Tram preparation** • Check-out/Check-in vehicle • Remove stop shoes • Request tram hold • Manage appropriate and safe conditions • Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction • Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream • Define mission • Set routes • Dispatch orders • Determine ATO state

	• Register autonomous tram unit • Provide vehicle database • Be identified like an autonomous tram • Determine/verify and transmit JP data • Determine/verify and transmit MP data • Determine mission data • Manage mission execution • Trigger events • Receive anomalies in task or mission execution • Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage climatization • Manage windscreen cleaning • Manage exterior lighting • Manage the bell • Manage tram modes • Manage cab control **Monitor Tram conditions** • Manage reporting • Supervise trams • Monitor fire alarm • Monitor tram unit failures • Monitor pantograph • Monitor battery protection mode • Measure tram's speed • Provide UTC time • Receive status report • Monitor trams • Transmit driving anomalies

	• Transmit periodically tram's location **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track • Interpret lineside signalling including vertical signs • Interpret semaphore phases **Tram movement** • Manage journey • Perform shunting • Provide acceleration • Provide Brake Command for Parking Braking • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Provide Brake Command for Emergency Braking • Acquire realised braking effort • Detect sliding • Apply and release braking forces • Check ad hoc brake release • Stop exactly at the intended location • Respect JP Timing Points and Optimize the consumption • Control initial traction effort • Calculate expected traction effort • Determine maximum authorised speed • Regulate traction and braking effort • Detect that final stopping point has been reached • Change running direction • Manage communication exchanges with driver

	• Monitor speed and distance • Supervise runaway movement • Transmit supervision orders • Transmit Emergency Stop • Manage stopping points and passing points • Command Emergency Brake **Events management** • Assist troubleshooting • Manage tram incidents

Table 16: Logical functions needed for UC.5.6.2.2.1 (Automatized function in green, Remote functions or partianlly automatized in orange and Manual functions in tram unit in red)

Operational use case for Wheel profile examination

Table 17 summarizes the operation use case for Wheel profile examination and it was defined in R2DATO Task 5.6 [1].

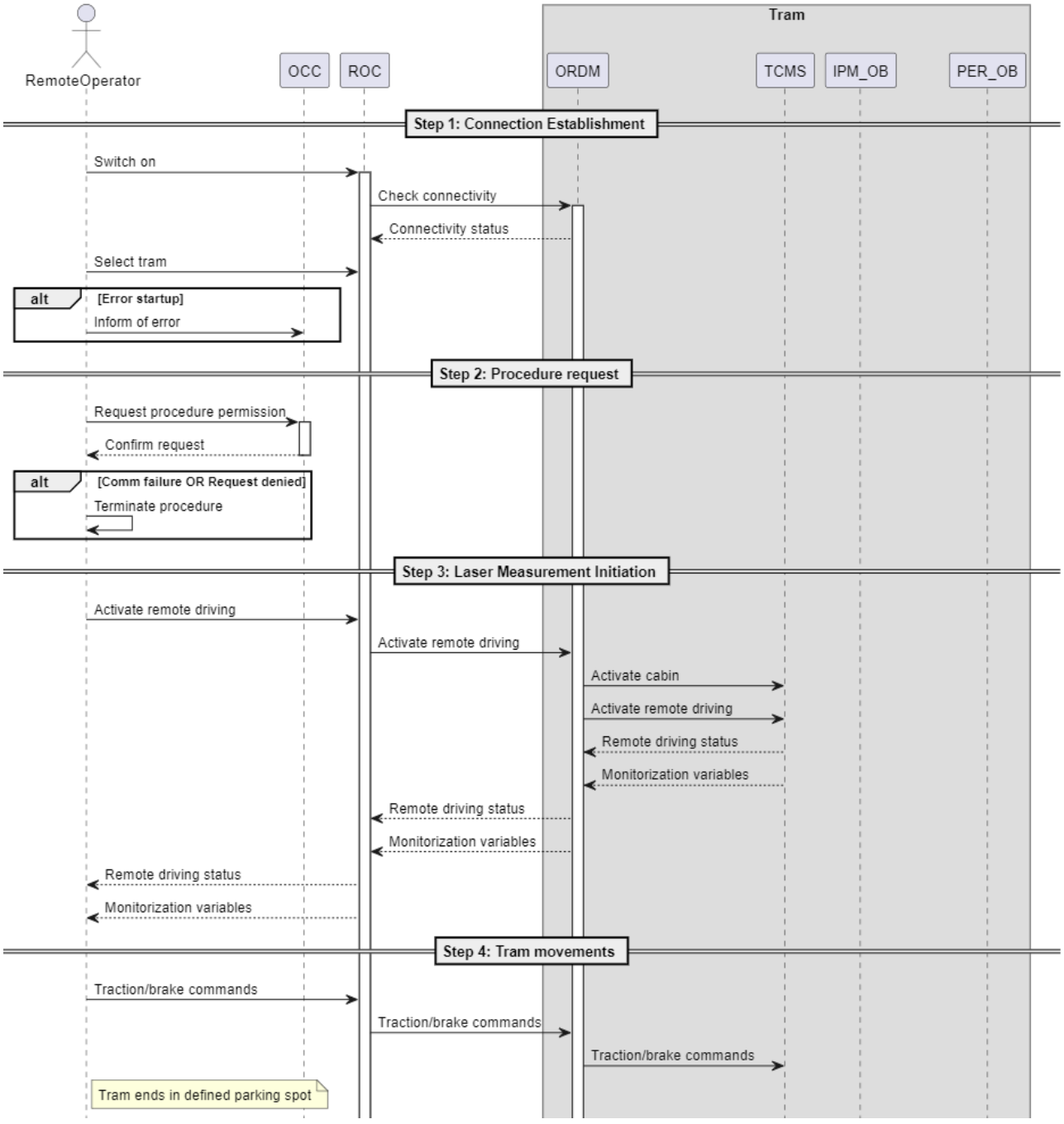
Use case field	Description	
ID	UC. 5.6.10.3	
Use case name	*Wheel profile examination*	
Main actor	*Tram remote driver-operator (remote operator)*	
Other actors	*Control centre operator or operations management room (at the depot) (OCC)*	
Use case summary	*This use case involves the remote operator establishing a connection with a tram and following specific instructions for wheel profile examination. The remote operator initiates laser measurements and controls the tram to move at shunting speed until all the wheels pass through the laser. After the measurement, they complete specific protocols defined by the network operator.*	
Applicability	• *Geographical: Europe* • *Operational category: Urban*	
Main goal	*The main goal of this use case is to optimise the precise measurement of a tram's wheelbase using laser technology in remote driving regime.*	
Preconditions	• *The tram is in remote driving regime and ready for measurement.* • *Communication between the remote operator and the tram is established.*	
Termination outcome	**Successful outcomes**	*The laser measurement of wheels is completed accurately and without issues.*
	Unsuccessful outcomes	*The tram fails to follow the procedure.*
Condition affecting termination outcome	**Outcome 2**	• *The connection between the remote operator and the tram is disrupted.* • *Obstacles on the tracks prevent the procedure's continuation.*
Use case scenario	**Step 1**	*Connection Establishment* *The remote operator establishes connection with the tram.*
	Step 1.1	*Communication issues prevent connection. The remote operator must report the issue to the OCC.*

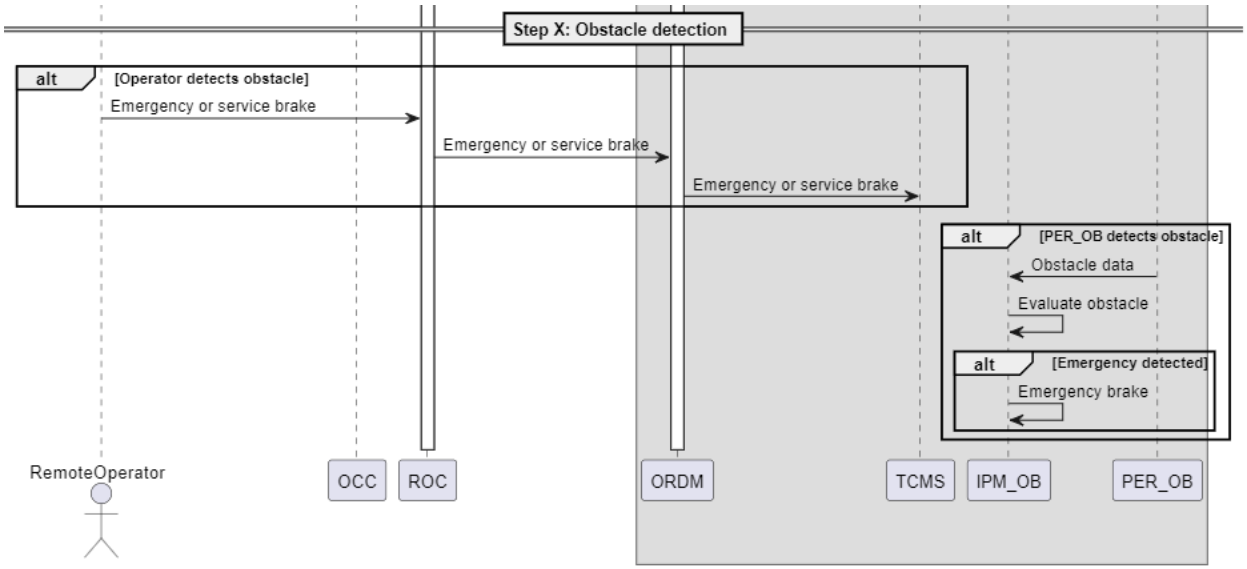
Step 2	*Send the procedure request to* the OCC. *The remote operator sends the request for wheels measurement procedure to the OCC. The OCC confirms the request.*
Step 2.1	*The communication with OCC fails or the request is rejected. The procedure is terminated.*
Step 3	*Laser Measurement Initiation* *The remote operator initiates the control of the vehicle in order to reach laser measurement equipment.*
Step 4	*Tram movements* *The remote operator controls the tram at the shunting speed until all the wheels are measured then proceeds to the defined parking spot according to the confirmed route.*
Step X	*If at any moment of the procedure the obstacle appears on the tracks, the remote operator must terminate the procedure, otherwise, the advanced driving assistance system initiates emergency braking.*
Postcondition	*Successful execution of procedure. The tram is parked on the pre-defined parking spot.*
Use case notes	*This use case describes the process of measuring a tram's wheels using laser technology and remote driving regime.* *This Use Case has the following links with the operational rules (D5.6 Annex 2):* • *OR.00.01 Communication with OCC* • *OR.00.02 End of communication with OCC* • *OR.00.05 Reporting defects and faults* • *OR.02.07 Track obstacles check before driving* • *OR.03.13 Acoustic signal before driving* • *OR.03.14 Detect obstacle (object in the or near track)*

Table 17: Use case “Wheel profile examination” description

Sequence Diagram for Wheel profile examination

5.6.10.3: Wheel profile examination





Logical Functions needed for Operational Use Case

Operational Use Case	Logical Functions
Wheel profile examination (UC.5.6.10.3)	**Tram preparation** • Check-out/Check-in vehicle • Request tram wake-up • Supervise tram wake-up • Manage Tram Preparation Staff request • Authorise Staff Responsible movements • Protect collection devices and catenary • Manage electrical energy for traction • Manage energy supply for auxiliaries • Provide remote control • Request video • Provide video stream • Remove stop shoes • Manage appropriate and safe conditions • Manage Remote Driver request • Request tram hold

	• Maintain tram physically immobilized • Set stop shoes if necessary • Supervise emergency brake chain test • Forbid start **Tram Subsystem Management** • Manage windscreen cleaning • Manage exterior lighting • Manage the bell • Manage trams modes • Manage cab control • Inhibit sanding **Monitor Tram conditions** • Supervise trams • Monitor fire alarm • Monitor pantograph • Monitor battery protection mode • Measure tram's speed • Provide UTC time • Monitor trams • Transmit periodically tram's location • Manage reporting • Monitor tram unit failures • Receive status report • Transmit driving anomalies **Perception** • Detect obstacles • Check if the surroundings (except signalling) oppose the departure • Detect person struck by a tram • Localize vehicle (track/direction/position/heading) • Detect railway agents on or along the tracks • Detect vehicle or buffer stop on the same track

	Tram movement • Drive tram remotely • Perform shunting • Provide Brake Command for Parking Braking • Provide acceleration • Provide Brake Command for Service Braking • Provide Brake Command for Holding Braking • Acquire realised braking effort • Detect sliding • Provide Brake Command for Emergency Braking • Apply and release braking forces • Check ad hoc brake release • Process remote driving commands • Monitor speed and distance • Command Emergency Brake • Transmit Emergency Stop • Determine maximum authorised speed • Supervise runaway movement **Events management** • Assist troubleshooting • Manage tram incidents

Table 18: Logical functions needed for UC.5.6.10.3 (Automatized function in green, Remote functions in orange and Manual functions in tram unit in red)

7. ATO ARCHITECTURE AND INTERFACE SPECIFICATION

This section describes the general architecture and the interface specification of the Automatic Train Operation (ATO) system for trams. The ATO architecture includes not only the capability to execute autonomous manoeuvres (controlling the speed, acceleration, braking, and tram subsystems), but also allow the remote control and driving of trams in controlled areas.

This section introduces a general architecture for ATO in tramway, describing the functional elements that form this architecture, defining the interfaces of each element, including the packets used in each interface.

Lately, the packets needed for address the logical functions identified for the execution of the Functional use cases presented in Section 6.

GENERAL ARCHITECTURE

Figure 3 depict the general ATO architecture for tramways. This architecture includes both, onboard elements and trackside elements.

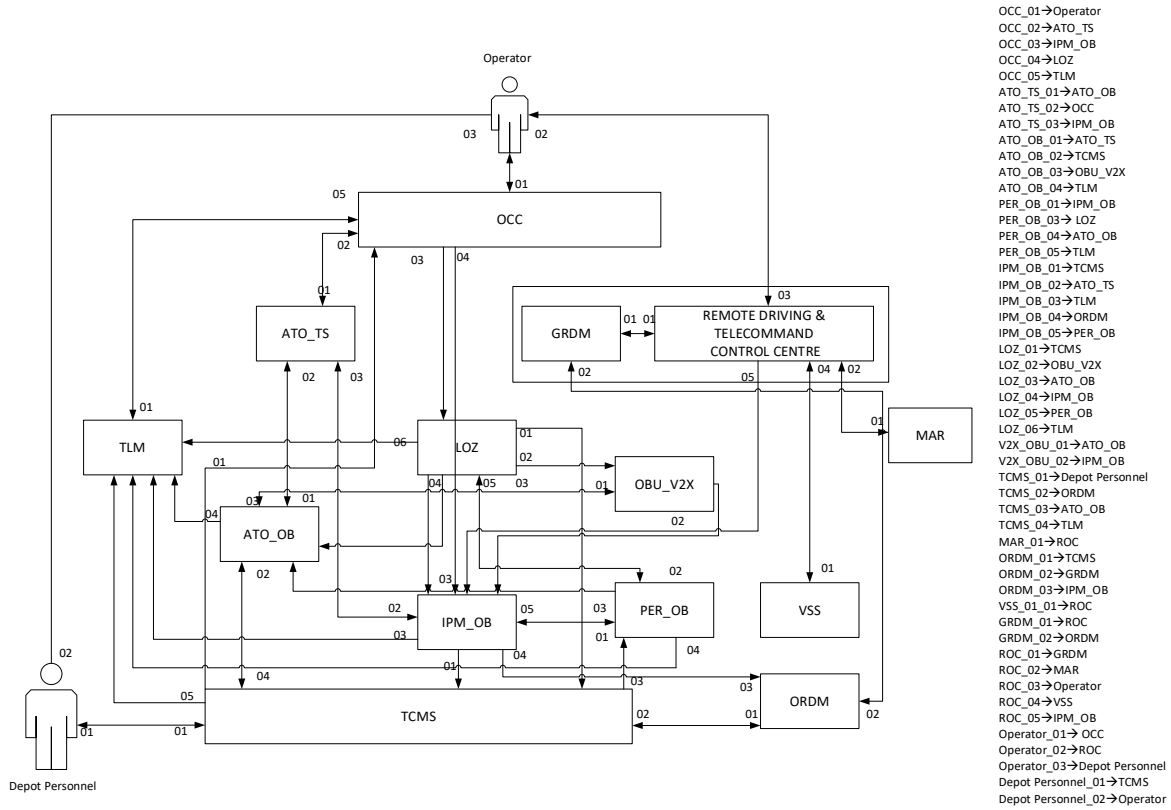


Figure 3: General ATO architecture for tramway

The onboard elements of the architecture are:

Telemetry system (TLM)

This logical component sends from tram to ground real-time information of any other on-board system in the tram.

Automatic Tram Operation – On-Board system (ATO_OB)

This logical component automatizes the tram operation substituting some of the driver and maintenance personnel functions carried out in the tram unit.

Incident Protection Management – On-Board system (IPM_OB)

This logical component supervises the movements and actions taken by the ATO_OB, together with the surrounding environment, evaluates the safety risk and takes actions to guarantee that the tram unit is in safe condition.

Tram Safe Location System (LOZ)

This logical component is deployed in the tram and calculates the safe location in the track making use of different information means.

Vehicle-to-everything module (V2X)

This logical component is deployed in the tram and it is used to communicate with other vehicles, urban infrastructure and vulnerable road users using ITS-G5 messages.

Perception – On-Board system (PER_OB)

This logical component is deployed in the tram and it implements algorithms to detect surrounding environment of the tram including traffic signs, other vehicles and people around, identifying risky situations, combining information from independent means, e.g. cameras, LiDAR, radar, etc.

Video Streaming System (VSS)

This logical component is deployed in the tram and it sends streams of the camera from the cabins of the tram unit to the remote cabin sited in the Remote Driving & Telecommand Control Centre.

Mobile Access Router (MAR)

This logical component is deployed in the tram and provides secure connectivity with trackside. Moreover, it remains on, connected to battery, when the tram is switched off and provides a digital output which allows starting the awaking routine remotely.

On-Board Remote Driving Module (ORDM)

This logical component is deployed in the tram and it communicates the tram unit with the remote cabin sited in the Remote Driving & Telecommand Control Centre. It retrieves tram TCMS different subsystem status info and transmits it to the remote cabin and it retrieves remote commands from the remote cabin and translates them to TCMS commands.

The trackside elements of the architecture are:

Remote Control Operator (ROC)

The Remote Control Operator connects remotely to the tram from the Remote Driving & Telecommand Operation Centre (ROC). The Remote Control Operator can remotely wake-up a tram unit, check tram unit status, command tram subsystems and drive the tram. These actions are restricted to geographical areas and situations designated by the tramway operator’s rules, which generally are: operations in depot and rescue operations in case the autonomous tram unit does not behave as expected. On all occasions remote driving is operator without passengers.

Remote Control Operator covers functions performed by other actors in legacy operations such as the Driver, the Tram Preparation Staff, the Shunting Personnel and the Washing Personnel.

Automatic Tram Operation – Trackside system (ATO_TS)

This logical component is deployed in the trackside and collects the manoeuvres and actions to be made by the tram unit from the OCC and its transfers them to the ATO_OB in a comprehensive format for the autonomous tram.

Remote Driving & Telecommand Operation Centre (ROC)

This component is placed in the OCC and it is used to connect, to retrieve information, including cameras of the cabins and to send commands to the remote tram.

Ground Remote Driving Module (GRDM)

This logical component is deployed in ground and handles the communications between different ROCs and ORDMs.

Operation and Control Centre (OCC)

The Operation and Control Centre is a system which provides to the Operator a complete visualization and control of all subsystems of the tramway system to guarantee its optimal operation controlling the fleet during operation. In ATO ecosystem it is expected that the Traffic Management System and the equipment to set the routes safety, i.e. change the track switches safely, is placed within the OCC.

Table 19 summarizes the matching between each functional element of the architecture illustrated in Figure 3, with each interface and with the corresponding packets used by each interface.

Functional element	Interface	Packet Names
OCC	OCC_01->Operator	• None (Manual via HMI)
	OCC_02->ATO_TS	• OCC_ATO_TS_COMMAND
	OCC_03->IPM_OB	• LOAD_DIGITAL_MAP
	OCC_04->LOZ	• LOAD_DIGITAL_MAP
	OCC_04->TLM	• OCC_TLM_REQUEST
ATO_TS	ATO_TS_01->ATO_OB	• ATO_TS_ATO_OB_COMMAND
	ATO_TS_02->OCC	• ATO_TS_OCC_STATUS
	ATO_TS_03->IPM_OB	• ATO_IPM_JOURNEY
ATO_OB	ATO_OB_01->ATO_TS	• ATO_OB_ATO_TS_STATUS
	ATO_OB_02->TCMS	• ATO_OB_TCMS_COMMAND
	ATO_OB_03->OBU_V2X	• V2X_ENABLE_DISABLE
	ATO_OB_04->TLM	• ATO_OB_TELEMETRY_STATUS
PER_OB	PER_OB_01->IPM_OB	• OBJ_DETECTION PER_OBSTACLE_DETECTIONS PER_VISUAL_EVENT_DETECTION • PER_STATE
	PER_OB_02->LOZ	• PER_LOCATION
	PER_OB_03->ATO_OB	• PER_OBSTACLE_DETECTIONS PER_VISUAL_EVENT_DETECTION • PER_STATE
	PER_OB_04->TLM	• PER_OB_TELEMETRY_STATUS
IPM	IPM_OB_01->TCMS	• IPM_EMEGERCY_BRAKE
	IPM_OB_02->ATO_TS	• IPM_OB_ATO_TS_ACK
	IPM_OB_03->TLM	• IPM_OB_TELEMETRY_STATUS
	IPM_OB_04->ORDM	• IPM_STATUS
	IPM_OB_04->PER_OB	• IPM_PER_CONFIGURATION • IPM_PER_OBSTACLE_DETECTION_REQUEST

		• IPM_PER_VISUAL_EVENT_DETECTION_REQUEST • IPM_PER_TRACK_CONDITIONS
LOZ	LOZ_01->TCMS	• UT_LOCATION_SPEED_LOCATION
	LOZ_02->OBU_V2X	• UT_LOCATION_SPEED_LOCATION
	LOZ_03->ATO_OB	• UT_LOCATION_SPEED_LOCATION
	LOZ_04->IPM_OB	• UT_LOCATION_SPEED_LOCATION
	LOZ_05->PER_OB	• UT_LOCATION_SPEED_LOCATION
	LOZ_06->TLM	• LOZ_TELEMETRY_STATUS
OBU	OBU_V2X_01->ATO_OB	• V2X_COLLISION_DETECTION • V2X_TSR_WORKS_ZONE • V2X_GLOSA • V2X_PRIORITY • V2X_EVW
	OBU_V2X_02->IPM_OB	• V2X_COLLISION_DETECTION • V2X_TSR_WORKS_ZONE • V2X_GLOSA • V2X_PRIORITY • V2X_EVW
TCMS	TCMS_01->Depot Personnel	• None (Manual via HMI)
	TCMS_02->ORDM	• COMM_STATUS_UT • UT_STATUS • RD_MONIT • RD_ALARMS
	TCMS_03->ATO_OB	• TCMS_ATO_MODE_ENABLE_DISABLE • TCMS_ATO_OB_UT_STATUS • TCMS_ATO_OB_UT_ALARMS
	TCMS_04->PER_OB	• TCMS_PER_OB_STATUS
	TCMS_05->TLM	• TCMS_TELEMETRY_STATUS
MAR	MAR_01->ROC	• UT_AWAKE_STATUS
ORDM	ORDM_01->TCMS	• COMM_STATUS_ROC • RD_CONTROL

		• RD_DRIVING • ROC_STATUS
	ORDM_02->GRDM	• COMM_STATUS_UT • UT_STATUS • RD_MONIT • RD_ALARMS
	ORDM_03->IPM _OB	• IPM_ENABLE_DISABLE
VSS	VSS_01_01->ROC	• VSS_VIDEO_STREAM
GRDM	GRDM_01->ROC	• COMM_STATUS_UT • UT_STATUS • RD_MONIT • RD_ALARMS
	GRDM_02->ORDM	• COMM_STATUS_ROC • RD_CONTROL • RD_DRIVING • ROC_STATUS •
ROC	ROC_01->GRDM	• COMM_STATUS_ROC • RD_CONTROL • RD_DRIVING • ROC_STATUS
	ROC_02->MAR	• UT_AWAKE_CONTROL
	ROC_03->Operator	• None (Manual via HMI)
	ROC_04->VSS	• VSS_VIDEO_REQUEST
	ROC_05->IPM_OB	• ROC_EMERGENCY_BRAKE
Operator	Operator_01->OCC	• None (Manual via HMI)
	Operator_02->ROC	• None (Manual via HMI)
	Operator_03->Depot Personnel	• None (Manual via TETRA)
Depot Personnel	Depot Personnel_01->TCMS	• None (Manual via HMI)
	Depot Personnel_02->Operator	• None (Manual via TETRA)

Table 19: Functional element, interface and packet relation

In the following tables each packet name is described, including the sources of it, the sinks, protocols (if it is defined) and the description of the information it carries, among other things. For those cases where the protocol has not defined it has been indicated and it will be object of discussion within the T10.2 based on different alternatives.

Packet Name		UT_AWAKE_CONTROL	
Source	ROC	**Sink**	MAR
Protocol	SNMPv3	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Command awaking or sleeping	

Packet Name		UT_AWAKE_STATUS	
Source	MAR	**Sink**	ROC
Protocol	SNMPv3	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Retrieve the current status (awake or sleeping)	

Packet Name		COMM_STATUS_ROC	
Source	ROC, GRDM	**Sink**	GRDM, ORDM
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Communication channel control to address SRR-2019	

Packet Name		RD_CONTROL	
Source	ROC, GRDM	**Sink**	GRDM, ORDM
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		Static UT control commands	

Packet Name		RD_DRIVING	
Source	ROC, GRDM	**Sink**	GRDM, ORDM
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	128ms

Description of transmitted information	Dynamic UT control commands

Packet Name		ROC_STATUS	
Source	ROC, GRDM	**Sink**	GRDM, ORDM
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		ROC aliveness message	

Packet Name		COMM_STATUS_UT	
Source	ORDM, GRDM	**Sink**	GRDM, ROC
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Communication channel control to address SRR-2019	

Packet Name		UT_STATUS	
Source	ORDM, GRDM	**Sink**	GRDM, ROC
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		UT status info (speed, position, TCMS train mode, trainID, serviceID and TCMS aliveness), ref SRR-2002	

Packet Name		RD_MONIT	
Source	ORDM, GRDM	**Sink**	GRDM, ROC
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		UT subsystem status	

Packet Name		RD_ALARMS	
Source	ORDM, GRDM	**Sink**	GRDM, ROC
Protocol	MQTT	**Datatype**	Process Data
		Cycle time	1024ms

Description of transmitted information	UT alarms

Packet Name		VSS_VIDEO_REQUEST	
Source	ROC	**Sink**	VSS
Protocol	RSTP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Video Stream request	

Packet Name		VSS_VIDEO_STREAM	
Source	VSS	**Sink**	ROC
Protocol	RSTP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Video stream with end-to-end latency information embedded (to address SRR-2003)	

Packet Name		RD_CONTROL	
Source	ORDM	**Sink**	TCMS
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		Static UT control commands	

Packet Name		RD_DRIVING	
Source	ORDM	**Sink**	TCMS
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		Dynamic UT control commands	

Packet Name		ROC_STATUS	
Source	ORDM	**Sink**	TCMS
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		ROC aliveness message	

Packet Name		COMM_STATUS_UT	
Source	TCMS	**Sink**	ORDM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Communication channel control to address SRR-2019	

Packet Name		UT_STATUS	
Source	TCMS	**Sink**	ORDM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		UT status info (speed, position, TCMS train mode, trainID, serviceID and TCMS aliveness)	

Packet Name		RD_MONIT	
Source	TCMS	**Sink**	ORDM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		UT subsystem status	

Packet Name		RD_ALARMS	
Source	TCMS	**Sink**	ORDM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		UT alarms	

Packet Name		UT_LOCATION_SPEED	
Source	LOZ	**Sink**	TCMS, IPM_OB, ORDM, ATO_OB, V2X_OB, PER_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Location and speed calculation.	

	Speed for overspeed control (SRR-2001) and location for zone surpass control (SRR-2005) Speed calculation to address SRR-2002 Speed calculation to address SRR-2023

Packet Name		ROC_EMERGENCY_BRAKE	
Source	ROC	**Sink**	IPM_OB
Protocol	Not defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Remote Emergency stop signal	

Packet Name		IPM_EMEGERCY_BRAKE	
Source	IPM_OB	**Sink**	TCMS
Protocol	Safe IO	**Datatype**	Digital output
		Cycle time	Sporadic
Description of transmitted information		Zone surpass control to address SRR-2005, Overspeed control to address SRR-2001 or SRR-2023	

Packet Name		OBJ_DETECTION	
Source	PER_OB	**Sink**	IPM_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Forward obstacle detection within a predefined distance. Safe obstacle detection to address SRR-2021 and SRR-2022	

Packet Name		IPM_STATUS	
Source	IPM_OB	**Sink**	ORDM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		IPM status	

Packet Name	IPM_ENABLE_DISABLE

Source	ORDM	**Sink**	IPM_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Enable/Disable obstacle detection (needed for washing)	

Packet Name		LOAD_DIGITAL_MAP	
Source	OCC	**Sink**	LOZ, IPM_OB
Protocol	Not defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Load the digital map from the OCC to the UT	

Packet Name		PER_LOCATION	
Source	PER_OB	**Sink**	LOZ
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		Provides data related to location of UT, such as relevant elements in the map and track where the UT is.	

Packet Name		PER_OBSTACLE_DETECTIONS	
Source	PER_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		• ODS status for obstacle detection function. • The track ahead free distance is the minimum distance between the infrastructure geometric distance, the first obstacle distance (if any detected) and the sensor efficiency distance • Type of area to be crossed. • Numbers of obstacles detected • Identifier of the kth obstacle detected • Class of the kth obstacle detected	

	• Estimated height of the kth obstacle detected [m] • Estimated width of the kth obstacle detected [m] • Minimum distance from the front end of the train to the projection on the track axis of the kth obstacle detected [m] • "Estimated longitudinal displacement of the kth obstacle detected along track axis [m/s]" • Minimum distance of the kth obstacle detected to ego track border [m] "Estimated lateral displacement of the kth obstacle detected orthogonally from track axis [m/s]" • Time, in milliseconds since start-up, when data in which kth obstacle has been detected were acquired. • Sensor 0 status used for obstacle detection • Sensor 1 status used for obstacle detection • Sensor 2 status used for obstacle detection • Sensor 3 status used for obstacle detection • Sensor 4 status used for obstacle detection • Sensor 5 status used for obstacle detection • "6D positioning of vehicle unavailable or invalid" • Track mapping unavailable or invalid Track conditions invalid

Packet Name		PER_VISUAL_EVENT_DETECTION	
Source	PER_OB	**Sink**	ATO_OB, IPM_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	64ms
Description of transmitted information		• VED status for visual event detection function	

	• Number of areas with specific track conditions transmitted in the packet • Type of area to be crossed. • Numbers of visual events detected • Identifier of the kth visual event detected • Identifier of object related to the kth visual event • Zone where the kth visual event is located • Class of the kth visual event detected • Attribute of the kth visual event detected • Estimated height of the kth visual event detected [m] • Estimated width of the kth visual event detected [m] • Estimated distance from the front end of the train along track axis to the nearest projection on the track axis of the kth visual event detected [m] • "Estimated longitudinal displacement of the kth obstacle detected along track axis [m/s]" • Estimated distance of the kth visual event detected to track [m] • "Estimated lateral displacement of the kth visual event detected orthogonally from track axis [m/s]" • Time, in milliseconds since start-up, when data in which kth visual event has been detected were acquired. • Sensor 0 status used for visual event detection • Sensor 1 status used for visual event detection • Sensor 2 status used for visual event detection • Sensor 3 status used for visual event detection

	• Sensor 4 status used for visual event detection • Sensor 5 status used for visual event detection • "6D positioning of vehicle unavailable or invalid" • Track mapping unavailable or invalid Track conditions invalid

Packet Name		PER_STATE	
Source	PER_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		PER_OB status	

Packet Name		IPM_PER_CONFIGURATION	
Source	IPM_OB	**Sink**	PER_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		Indicate the current active cab considered by IPM	

Packet Name		IPM_PER_OBSTACLE_DETECTION_REQUEST	
Source	IPM_OB	**Sink**	PER_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Qualifier for resuming the data to be considered for the obstacle detection request. • Qualifier defining the detection mode of the Obstacles Detection function • Distance of observation requested by IPM for obstacle detection, this distance is defined considering the vehicle front end as reference Number of micro-mapping nodes for relevant area of interest.	

	○ Latitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train. ○ Longitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train. ○ Altitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train.

Packet Name		IPM_PER_VISUAL_EVENT_DETECTION_REQUEST	
Source	IPM_OB	**Sink**	PER_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Qualifier for resuming the data to be considered for the visual event detection request. • Distance of observation requested by IPM for visual event detection, this distance is defined considering the vehicle front end as reference Number of micro-mapping nodes for relevant area of interest. ○ Latitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train. ○ Longitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train. ○ Altitude (WGS84) of the micro-mapping node (k) corresponding to the centre of the track travelled by the train.	

Packet Name		IPM_PER_TRACK_CONDITIONS	
Source	IPM_OB	**Sink**	PER_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Qualifier for resuming the track conditions	

	• Number of areas with specific track conditions transmitted in the packet Type of area to be crossed.
	  ○ Latitude (WGS84) of the micro-mapping node (k) corresponding to the entry in the area with specific track conditions.
	  ○ Longitude (WGS84) of the micro-mapping node (k) corresponding to the entry in the area with specific track conditions.
	  ○ Altitude (WGS84) of the micro-mapping node (k) corresponding to the entry in the area with specific track conditions.

Packet Name		ATO_TS_ATO_OB_COMMAND	
Source	ATO_TS	**Sink**	ATO_OB
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Set journey • Stop automatic operation • Request auto-checks • Grant approval	

Packet Name		ATO_OB_ATO_TS_STATUS	
Source	ATO_TS	**Sink**	ATO_OB
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Request approval • Obstacle data • Check results • Acknowledge journey • Relevant object detected • Vehicle database	

Packet Name		ATO_TS_OCC_STATUS	
Source	ATO_TS	**Sink**	OCC
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Request approval • Report error • Obstacle data • Relevant object detected • Vehicle datadase	

Packet Name		OCC_ATO_TS_COMMAND	
Source	OCC	**Sink**	ATO_TS
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Stop automatic operation • Grant approval • Define mission and journey	

Packet Name		ATO_IPM_JOURNEY	
Source	ATO_TS	**Sink**	IPM_OB
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Set journey	

Packet Name		IPM_OB_ATO_TS_ACK	
Source	IPM_OB	**Sink**	ATO_TS
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Acknowledge journey	

Packet Name	ATO_OB_TCMS_COMMAND

Source	ATO_OB	**Sink**	TCMS
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Activate shunting mode • Deactivate shunting mode • Brake • Traction/brake commands	

Packet Name		TCMS_ATO_MODE_ENABLE_DISABLE	
Source	TCMS	**Sink**	ATO_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Active/Disable mode	

Packet Name		TCMS_ATO_OB_UT_STATUS	
Source	TCMS	**Sink**	ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• UT subsystem status	

Packet Name		TCMS_ATO_OB_UT_ALARMS	
Source	TCMS	**Sink**	ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• UT alarms	

Packet Name		TCMS_PER_OB_STATUS	
Source	TCMS	**Sink**	PER_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms

Description of transmitted information	• Active Cab

Packet Name		V2X_ENABLE_DISABLE	
Source	ATO_OB	**Sink**	V2X_OB
Protocol	TRDP	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• V2X enabling/disabling	

Packet Name		V2X_COLLISION_DETECTION	
Source	V2X_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Longitudinal and intersectional obstacles detection based on V2X CAM messages • Class of the kth V2X event detected • Attribute of the kth V2X event detected • Estimated height of the kth V2X event detected [m] • Estimated width of the kth V2X event detected [m] • Estimated distance from the front end of the train along track axis to the nearest projection on the track axis of the kth V2X event detected [m] • "Estimated longitudinal displacement of the kth obstacle detected along track axis [m/s]" • Estimated distance of the kth V2X event detected to track [m] • "Estimated lateral displacement of the kth V2X event detected orthogonally from track axis [m/s]"	

Packet Name		V2X_TSR_WORKS_ZONE	
Source	V2X_OB	**Sink**	IPM_OB, ATO_OB

Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Temporal Speed Limitation or Road Works Zone advertised by V2X IVIM messages	

Packet Name		V2X_GLOSA	
Source	V2X_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Green Light Optimal Speed Advisory in semaphores using V2X SPATEM messages.	

Packet Name		V2X_PRIORITY	
Source	V2X_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Intersection priority management based on SREM and SSEM V2X messages	

Packet Name		V2X_EVW	
Source	V2X_OB	**Sink**	IPM_OB, ATO_OB
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	128ms
Description of transmitted information		• Emergency vehicle warning based on DENM and CAM V2X messages	

Packet Name		ATO_OB_TELEMETRY_STATUS	
Source	ATO_OB	**Sink**	TLM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• Report periodically variable status of ATO-OB to TLM	

Packet Name		IPM_OB_TELEMETRY_STATUS	
Source	IPM_OB	**Sink**	TLM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• Report periodicaly variable status of IPM-OB to TLM	

Packet Name		TCMS_TELEMETRY_STATUS	
Source	TCMS	**Sink**	TLM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• Report periodically variable status of TCMS to TLM	

Packet Name		LOZ_TELEMETRY_STATUS	
Source	LOZ	**Sink**	TLM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• Report periodically variable status of LOZ to TLM	

Packet Name		PER_OB_TELEMETRY_STATUS	
Source	PER_OB	**Sink**	TLM
Protocol	TRDP	**Datatype**	Process Data
		Cycle time	1024ms
Description of transmitted information		• Report periodically variable status of PER_OB to TLM	

Packet Name		TLM_OCC_STATUS	
Source	TLM	**Sink**	OCC
Protocol	Not Defined	**Datatype**	Process Data
		Cycle time	1024ms

Description of transmitted information	• Report periodically variable status of monitored onboard systems to OCC

Packet Name		OCC_TLM_REQUEST	
Source	TLM	**Sink**	OCC
Protocol	Not Defined	**Datatype**	Message Data
		Cycle time	Sporadic
Description of transmitted information		• Request variables to be monitored	

LIST OF PACKET NEEDED BY LOGICAL FUNCTION

This section presents the relation between logical functions of Section 5 and the packets introduced in the previous subsection. Table 20 summarizes this relation between packets and logical functions. It is worth noting that each logical function may be addressed using different packets and different functional elements whether it is executed by remote control/driving or by autonomous movement.

Logical Function	Function Group	Packet name (Remote Driving)	Packet name (Autonomous Movement)
Check-out/Check-in vehicle	Tram preparation	None (Manual)	None (Manual)
Request tram wake-up	Tram preparation	UT_AWAKE_CONTROL	UT_AWAKE_CONTROL
Supervise tram wake-up	Tram preparation	UT_AWAKE_STATUS	UT_AWAKE_STATUS
Manage Tram Preparation Staff request	Tram preparation	None (Manual)	-
Authorise Staff Responsible movements	Tram preparation	RD_CONTROL, RD_MONIT, RD_ALARMS	RD_CONTROL, RD_MONIT, RD_ALARMS
Protect collection devices and catenary	Tram preparation	Automatically done by TCMS	Automatically done by TCMS
Manage electrical energy for traction	Tram preparation	RD_CONTROL, RD_MONIT, RD_ALARMS	RD_CONTROL, RD_MONIT, RD_ALARMS, or ATO_TS_ATO_OB_COMMAND, ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS

Manage energy supply for auxiliaries	Tram preparation	RD_CONTROL, RD_MONIT, RD_ALARMS	RD_CONTROL, RD_MONIT, RD_ALARMS, or ATO_TS_ATO_OB_COMMAND, ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Provide remote control	Tram preparation	RD_CONTROL, RD_MONIT, RD_ALARMS	RD_CONTROL, RD_MONIT, RD_ALARMS
Request video	Tram preparation	VSS_VIDEO_REQUEST	VSS_VIDEO_REQUEST
Provide video stream	Tram preparation	VSS_VIDEO_STREAM	VSS_VIDEO_STREAM
Remove stop shoes	Tram preparation	None (Manual)	None (Manual)
Manage appropriate and safe conditions	Tram preparation	COMM_STATUS_ROC, COMM_STATUS_UT, VSS_VIDEO_STREAM, UT_STATUS, UT_SPEED_LOCATION, IPM_EMEGERCY_BRAKE	LOAD_DIGITAL_MAP, IPM_ENABLE_DISABLE, ATO_IPM_JOURNEY, IPM_OB_ATO_TS_ACK, IPM_PER_CONFIGURATION ,IPM_STATUS, PER_STATE, IPM_PER_OBSTACLE_DETECTION_REQUEST, IPM_PER_VISUAL_EVENT_DETECTION_REQUEST, PER_OBSTACLE_DETECTIONS, PER_VISUAL_EVENT_DETECTION, UT_LOCATION_SPEED, IPM_PER_TRACK_CONDITIONS, IPM_EMEGERCY_BRAKE, OBJ_DETECTION
Manage Remote Driver request	Tram preparation	RD_CONTROL, RD_MONIT, RD_ALARMS	RD_CONTROL, RD_MONIT, RD_ALARMS
Request tram hold	Tram preparation	None (Manual)	None (Manual)

Maintain tram physically immobilized	Tram preparation	None (Manual)	None (Manual)
Set stop shoes if necessary	Tram preparation	None (Manual)	None (Manual)
Supervise emergency brake chain test	Tram preparation	Automatically done by TCMS	Automatically done by TCMS
Forbid start	Tram preparation	None (Manual)	None (Manual)
Define mission	Tram preparation	NA	OCC_ATO_TS_COMMAND, ATO_TS_ATO_OB_COMMAND, ATO_IPM_JOURNEY
Set routes	Tram preparation	NA	None (Manual or third party)
Dispatch orders	Tram preparation	NA	OCC_ATO_TS_COMMAND, ATO_TS_ATO_OB_COMMAND, ATO_IPM_JOURNEY, IPM_OB_ATO_TS_ACK, ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Determine ATO state	Tram preparation	NA	ATO_TS_ATO_OB_COMMAND, ATO_OB_ATO_TS_STATUS
Register autonomous tram unit	Tram preparation	NA	ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Provide vehicle database	Tram preparation	NA	ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Be identified like an autonomous tram	Tram preparation	NA	Automatically done by TCMS

Determine/verify and transmit JP data	Tram preparation	NA	OCC_ATO_TS_COMMAND, ATO_TS_ATO_OB_COMMAND, ATO_IPM_JOURNEY, IPM_OB_ATO_TS_ACK, ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Determine/verify and transmit MP data	Tram preparation	NA	OCC_ATO_TS_COMMAND, ATO_TS_ATO_OB_COMMAND, ATO_IPM_JOURNEY, IPM_OB_ATO_TS_ACK, ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Determine mission data	Tram preparation	NA	OCC_ATO_TS_COMMAND, ATO_TS_ATO_OB_COMMAND, ATO_IPM_JOURNEY, IPM_OB_ATO_TS_ACK, ATO_OB_ATO_TS_STATUS, ATO_TS_OCC_STATUS
Manage mission execution	Tram preparation	NA	ATO_OB_TCMS_COMMAND
Trigger events	Tram preparation	NA	OCC_TLM_REQUEST, ATO_OB_TELEMETRY_STATUS, TCMS_TELEMETRY_STATUS, LOZ_TELEMETRY_STATUS, PER_OB_TELEMETRY_STATUS, TLM_OCC_STATUS
Receive anomalies in task or mission execution	Tram preparation	NA	OCC_TLM_REQUEST, ATO_OB_TELEMETRY_STATUS, TCMS_TELEMETRY_STATUS, LOZ_TELEMETRY_STATUS, PER_OB_TELEMETRY_STATUS, TLM_OCC_STATUS
Manage windscreen cleaning	Tram Subsystem Management	RD_CONTROL, RD_MONIT	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS

Manage exterior lighting	Tram Subsystem Management	RD_CONTROL, RD_MONIT	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Manage the bell	Tram Subsystem Management	RD_CONTROL, RD_MONIT	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Manage trams modes	Tram Subsystem Management	RD_CONTROL, RD_MONIT	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Manage climatization	Tram Subsystem Management	NA	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Manage cab control	Tram Subsystem Management	NA	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Supervise trams	Monitor Tram conditions	RD_MONIT, RD_ALARMS	TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Monitor fire alarm	Monitor Tram conditions	RD_ALARMS	TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Monitor pantograph	Monitor Tram conditions	RD_MONIT, RD_ALARMS	TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS

Monitor battery protection mode	Monitor Tram conditions	RD_MONIT, RD_ALARMS	TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Measure tram's speed	Monitor Tram conditions	RD_MONIT, UT_STATUS	TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Provide UTC time	Monitor Tram conditions	UT_STATUS	TCMS_ATO_OB_UT_STATUS, ATO_OB_ATO_TS_STATUS
Monitor trams	Monitor Tram conditions	RD_MONIT, UT_STATUS	TCMS_ATO_OB_UT_STATUS, ATO_OB_ATO_TS_STATUS
Transmit periodically tram's location	Monitor Tram conditions	UT_STATUS	TCMS_ATO_OB_UT_STATUS, ATO_OB_ATO_TS_STATUS
Manage reporting	Monitor Tram conditions	NA	OCC_TLM_REQUEST, TCMS_TELEMETRY_STATUS, TLM_OCC_STATUS
Monitor tram unit failures	Monitor Tram conditions	NA	OCC_TLM_REQUEST, ATO_OB_TELEMETRY_STATUS, TCMS_TELEMETRY_STATUS, LOZ_TELEMETRY_STATUS, PER_OB_TELEMETRY_STATUS, TLM_OCC_STATUS
Receive status report	Monitor Tram conditions	NA	OCC_TLM_REQUEST, ATO_OB_TELEMETRY_STATUS, TCMS_TELEMETRY_STATUS, LOZ_TELEMETRY_STATUS, PER_OB_TELEMETRY_STATUS, TLM_OCC_STATUS
Transmit driving anomalies	Monitor Tram conditions	NA	OCC_TLM_REQUEST, ATO_OB_TELEMETRY_STATUS, TCMS_TELEMETRY_STATUS, LOZ_TELEMETRY_STATUS, PER_OB_TELEMETRY_STATUS, TLM_OCC_STATUS
Detect obstacles	Perception	OBJ_DETECTION	OBJ_DETECTION, PER_OBSTACLE_DETECTIONS

Check if the surroundings (except signalling) oppose the departure	Perception	VSS_VIDEO_STREAM	OBJ_DETECTION, PER_OBSTACLE_DETECTIONS
Detect person struck by a tram	Perception	VSS_VIDEO_STREAM	OBJ_DETECTION, PER_OBSTACLE_DETECTIONS
Localize vehicle (track/direction/position/heading)	Perception	UT_LOCATION_SPEED_LOCATION	UT_LOCATION_SPEED_LOCATION, LOZ_TELEMETRY_STATUS, TLM_OCC_STATUS
Detect railway agents on or along the tracks	Perception	VSS_VIDEO_STREAM	OBJ_DETECTION, PER_OBSTACLE_DETECTIONS
Detect vehicle or buffer stop on the same track	Perception	VSS_VIDEO_STREAM	OBJ_DETECTION, PER_OBSTACLE_DETECTIONS, UT_LOCATION_SPEED, V2X_COLLISION_DETECTION
Interpret lineside signalling including vertical signs	Perception	NA	UT_LOCATION_SPEED, OBJ_DETECTION, PER_VISUAL_EVENT_DETECTION, V2X_TSR_WORKS_ZONE, V2X_GLOSA, V2X_PRIORITY
Interpret semaphore phases	Perception	NA	UT_LOCATION_SPEED, OBJ_DETECTION, PER_VISUAL_EVENT_DETECTION, V2X_TSR_WORKS_ZONE, V2X_GLOSA, V2X_PRIORITY
Drive tram remotely	Tram movement	RD_DRIVING, RD_MONIT	RD_DRIVING, RD_MONIT
Perform shunting	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND, TCMS_ATO_OB_UT_STATUS, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS
Provide Brake Command for Parking Braking	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND

Provide acceleration	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND
Provide Brake Command for Service Braking	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND
Provide Brake Command for Holding Braking	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND
Acquire realised braking effort	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Detect sliding	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Provide Brake Command for Emergency Braking	Tram movement	RD_DRIVING, RD_MONIT	ATO_OB_TCMS_COMMAND
Apply and release braking forces	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Check ad hoc brake release	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Process remote driving commands	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Monitor speed and distance	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Command Emergency Brake	Tram movement	RD_DRIVING, RD_MONIT	IPM_EMEGERCY_BRAKE
Determine maximum authorised speed	Tram movement	UT_LOCATION_SPEED_LOCATION, IPM_EMEGERCY_BRAKE	UT_LOCATION_SPEED, IPM_EMEGERCY_BRAKE

Supervise runaway movement	Tram movement	UT_LOCATION_SPEED_LOCATION, IPM_EMEGERCY_BRAKE	UT_LOCATION_SPEED, IPM_EMEGERCY_BRAKE
Manage journey	Tram movement	NA	ATO_OB_TCMS_COMMAND
Stop exactly at the intended location	Tram movement	NA	ATO_OB_TCMS_COMMAND, UT_LOCATION_SPEED
Respect JP Timing Points and Optimize the consumption	Tram movement	NA	ATO_OB_TCMS_COMMAND, UT_LOCATION_SPEED
Control initial traction effort	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Calculate expected traction effort	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Regulate traction and braking effort	Tram movement	Automatically done by TCMS	Automatically done by TCMS
Detect that final stopping point has been reached	Tram movement	NA	ATO_OB_TCMS_COMMAND, UT_LOCATION_SPEED
Change running direction	Tram movement	NA	ATO_OB_TCMS_COMMAND, UT_LOCATION_SPEED
Manage communication exchanges with driver	Tram movement	NA	NA
Transmit supervision orders	Tram movement	RD_CONTROL, RD_MONIT	RD_CONTROL, RD_MONIT
Transmit Emergency Stop	Tram movement	ROC_EMERGENCY_BRAKE, IPM_EMEGERCY_BRAKE	ROC_EMERGENCY_BRAKE, IPM_EMEGERCY_BRAKE

Manage stopping points and passing points	Tram movement	NA	ATO_OB_TCMS_COMMAND, UT_LOCATION_SPEED
Assist troubleshooting	Events management	RD_MONIT, UT_STATUS	Manual, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS, TLM_OCC_STATUS
Manage tram incidents	Events management	None (Manual)	Manual, TCMS_ATO_OB_UT_ALARMS, ATO_OB_ATO_TS_STATUS, TLM_OCC_STATUS

Table 20: List of packet needed by logical function

LIST OF PACKET NAMES BY OPERATIONAL USE CASE

Task 10.2 of R2DATO will build on the efforts of Task 6.6, advancing the development of various functions and interfaces in line with the architecture outlined in this document. This section is intended to direct Task 10.2 towards prioritizing the creation of interfaces that are crucial for implementing the operational use cases defined as a priority. The relation between Operational use cases coming from Deliverable 5.6 and packet names used in the interfaces of the architecture is summarized in Table 21.

Packet Name	UC.5.6.5.24	UC.5.6.5.25	UC.5.6.10.5	UC.5.6.2.3.1	UC.5.6.2.2.1	UC.5.6.10.3
UT_AWAKE_CONTROL	x	x	x			x
UT_AWAKE_STATUS	x	x	x			x
COMM_STATUS_ROC	x	x	x			x
RD_CONTROL	x	x	x			x
RD_DRIVING	x	x	x			x
ROC_STATUS	x	x	x			x
COMM_STATUS_ROC	x	x	x			x
RD_CONTROL	x	x	x			x
RD_DRIVING	x	x	x			x
ROC_STATUS	x	x	x			x
COMM_STATUS_UT	x	x	x			x
UT_STATUS	x	x	x			x
RD_MONIT	x	x	x			x
RD_ALARMS	x	x	x			x
COMM_STATUS_UT	x	x	x			x
UT_STATUS	x	x	x			x
RD_MONIT	x	x	x			x
RD_ALARMS	x	x	x			x
VSS_VIDEO_REQUEST	x	x	x			x
VSS_VIDEO_STREAM	x	x	x			x
COMM_STATUS_ROC	x	x	x			x
RD_CONTROL	x	x	x			x
RD_DRIVING	x	x	x			x
ROC_STATUS	x	x	x			x

COMM_STATUS_UT	x	x	x			x
UT_STATUS	x	x	x			x
RD_MONIT	x	x	x			x
RD_ALARMS	x	x	x			x
UT_LOCATION_SPEED	x	x	x	x	x	x
UT_LOCATION_SPEED	x	x	x	x	x	x
UT_LOCATION_SPEED	x	x	x			x
UT_LOCATION_SPEED	x	x	x			x
UT_LOCATION_SPEED	x	x	x			x
UT_LOCATION_SPEED	x	x	x			x
ROC_EMERGENCY_BRAKE	x	x	x	x	x	x
IPM_EMEGERCY_BRAKE	x	x	x	x	x	x
OBJ_DETECTION	x	x	x	x	x	x
IPM_STATUS						x
IPM_ENABLE_DISABLE						x
LOAD_DIGITAL_MAP	x	x	x	x	x	x
LOAD_DIGITAL_MAP	x	x	x	x	x	x
PER_LOCATION				x	x	
PER_OBSTACLE_DETECTIONS				x	x	
PER_VISUAL_EVENT_DETECTION				x	x	
PER_STATE				x	x	
IPM_PER_CONFIGURATION				x	x	
IPM_PER_OBSTACLE_DETECTION_REQUEST				x	x	
IPM_PER_VISUAL_EVENT_DETECTION_REQUEST				x	x	
IPM_PER_TRACK_CONDITIONS				x	x	
PER_OBSTACLE_DETECTIONS				x	x	
PER_VISUAL_EVENT_DETECTION				x	x	
PER_STATE				x	x	
ATO_TS_ATO_OB_COMMAND				x	x	
ATO_OB_ATO_TS_STATUS				x	x	
ATO_TS_OCC_STATUS				x	x	

OCC_ATO_TS_COMMAND				x	x	
ATO_IPM_JOURNEY				x	x	
IPM_OB_ATO_TS_ACK				x	x	
ATO_OB_TCMS_COMMAND				x	x	
TCMS_ATO_MODE_ENABLE_DISABLE				x	x	
TCMS_ATO_OB_UT_STATUS				x	x	
TCMS_ATO_OB_UT_ALARMS				x	x	
UT_LOCATION_SPEED					x	
V2X_ENABLE_DISABLE					x	
V2X_COLLISION_DETECTION					x	
V2X_TSR_WORKS_ZONE					x	
V2X_GLOSA					x	
V2X_PRIORITY					x	
V2X_EVW					x	
V2X_COLLISION_DETECTION					x	
V2X_TSR_WORKS_ZONE					x	
V2X_GLOSA					x	
V2X_PRIORITY					x	
V2X_EVW					x	
ATO_OB_TELEMETRY_STATUS				x	x	
IPM_OB_TELEMETRY_STATUS				x	x	
TCMS_TELEMETRY_STATUS				x	x	
LOZ_TELEMETRY_STATUS				x	x	
PER_OB_TELEMETRY_STATUS				x	x	
TLM_OCC_STATUS				x	x	
OCC_TLM_REQUEST				x	x	

Table 21: Packet needed for each Operational use case from D5.6

8. COMPARISON BETWEEN MANUAL OPERATIONS AND AUTONOMOUS/REMOTE OPERATIONS

This section compares the actors involved in the logical functions of the operational use cases discussed in Section 6. This comparison will show the potentiality of remote driving function and autonomous movements in terms of making the operation and maintenance more effective in time and cost. Table 22 summarizes the actors involved in each operation type. To facilitate the comprehension of the table, the functions that still require local personnel in the tram have been marked in orange, whereas the functions that can be fully automatize or made by a remote operator are market in green. As it can be seen, for the logical functions identified to address the operational use cases of T5.6 related to Remote Driving in depot, 77 out of 86 logical functions can be perform automatically or by a Remote Operator following the presented architecture in this deliverable. For the operational use cases related to autonomous manoeuvres 78 out of 87 logical functions can be performed automatically or by a Remote Operator.

Function Group	Logical Function	Actors in legacy operations in depot	Actors in Remote Driving in depot	Actors in Autonomous Manoeuvres in depot
Tram preparation	Check-out/Check-in vehicle	Driver, Shunting Personnel, Washing Personnel, Onboard Staff, Tram Preparation Staff, TCMS.	Tram Preparation Staff.	Tram Preparation Staff.
Tram preparation	Request tram wake-up	Driver, Shunting Personnel, Washing Personnel.	Remote Control Operator, MAR, TCMS.	Remote Control Operator, MAR, TCMS.
Tram preparation	Supervise tram wake-up	Driver, Shunting Personnel.	Remote Control Operator, MAR, TCMS.	Remote Control Operator, MAR, TCMS.
Tram preparation	Manage Tram Preparation Staff request	Depot Manager.	Depot Manager.	Depot Manager.
Tram preparation	Authorise Staff Responsible movements	Not Available.	OCC, Remote Control Operator, ORDM.	OCC, Remote Control Operator, ORDM.
Tram preparation	Protect collection devices and catenary	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram preparation	Manage electrical energy for traction	Driver, Shunting Personnel.	Remote Control Operator, ORDM.	Remote Control Operator, ATO_TS, ATO_OB.
Tram preparation	Manage energy supply for auxiliaries	Driver, Shunting Personnel.	Remote Control Operator, ORDM.	Remote Control Operator, ATO_TS, ATO_OB.
Tram preparation	Provide remote control	Not Available.	Remote Control Operator, ORDM.	Remote Control Operator, ORDM.

Tram preparation	Request video	Not Available.	Remote Control Operator, ORDM.	Remote Control Operator, ORDM.
Tram preparation	Provide video stream	Not Available.	Remote Control Operator, ORDM.	Remote Control Operator, ORDM.
Tram preparation	Remove stop shoes	Driver, Shunting Personnel.	Shunting Personnel.	Shunting Personnel.
Tram preparation	Manage appropriate and safe conditions	Driver, OCC.	OCC, Remote Control Operator, IPM_OB.	OCC, ATO_TS, ATO_OB, PER_OB, IPM_OB.
Tram preparation	Manage Remote Driver request	Not available.	ROC, ORDM.	ROC, ORDM.
Tram preparation	Request tram hold	Depot Manager, Workshop/Maintenance Manager, Safety and Technical Department, OCC.	Depot Manager, Workshop/Maintenance Manager, Safety and Technical Department, OCC.	Depot Manager, Workshop/Maintenance Manager, Safety and Technical Department, OCC.
Tram preparation	Maintain tram physically immobilized	Driver, Shunting Personnel.	Shunting Personnel.	Shunting Personnel.
Tram preparation	Set stop shoes if necessary	Driver, Shunting Personnel.	Shunting Personnel.	Shunting Personnel.
Tram preparation	Supervise emergency brake chain test	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram preparation	Forbid start	Driver, Shunting Personnel.	Shunting Personnel.	Shunting Personnel.
Tram preparation	Define mission	OCC, Driver.	OCC, Remote Control Operator.	OCC, ATO_TS, ATO_OB, IPM_OB.
Tram preparation	Set routes	OCC.	OCC.	OCC.
Tram preparation	Dispatch orders	Driver, Shunting Personnel, Washing Personnel, TCMS, OCC.	OCC, Remote Control Operator, ORDM.	OCC, ATO_TS, ATO_OB, IPM_OB.
Tram preparation	Determine ATO state	Not available.	Not available.	ATO_OB, ATO_TS.
Tram preparation	Register autonomous tram unit	Not available.	Not available.	ATO_OB, ATO_TS, OCC.

Tram preparation	Provide vehicle database	Not available.	Not available.	ATO_OB, ATO_TS, OCC.
Tram preparation	Be identified like an autonomous tram	Not available.	Not available.	Automatically done by TCMS
Tram preparation	Determine/verify and transmit JP data	Not available.	Not available.	OCC, ATO_TS, ATO_OB, IPM_OB.
Tram preparation	Determine/verify and transmit MP data	Not available.	Not available.	OCC, ATO_TS, ATO_OB, IPM_OB.
Tram preparation	Determine mission data	OCC (TMS).	OCC (TMS).	OCC (TMS), ATO_TS, ATO_OB, IPM_OB.
Tram preparation	Manage mission execution	Driver, Operations Manager.	Remote Control Operator.	ATO_OB.
Tram preparation	Trigger events	Driver, TCMS, Operational personnel at stations/stop.	Remote Control Operator.	OCC, TLM, ATO_OB, IPM_OB, PER_OB, LOZ.
Tram preparation	Receive anomalies in task or mission execution	Driver.	Remote Control Operator.	OCC, TLM, ATO_OB, IPM_OB, PER_OB, LOZ.
Tram Subsystem Management	Manage windscreen cleaning	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram Subsystem Management	Manage exterior lighting	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram Subsystem Management	Manage the bell	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram Subsystem Management	Manage trams modes	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram Subsystem Management	Manage climatization	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram Subsystem Management	Manage cab control	Driver, Washing Personnel, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.

Monitor Tram conditions	Supervise trams	Driver, Depot Manager, Workshop/Maintenance Manager, TCMS, OCC.	Remote Control Operator, ORDM.	TCMS, ATO_OB, ATO_TS.
Monitor Tram conditions	Monitor fire alarm	TCMS, Driver.	TCMS, ORDM, Remote Control Operator.	TCMS, ATO_OB, ATO_TS.
Monitor Tram conditions	Monitor pantograph	Driver, OCC.	TCMS, ORDM, Remote Control Operator.	TCMS, ATO_OB, ATO_TS.
Monitor Tram conditions	Monitor battery protection mode	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Monitor Tram conditions	Measure tram's speed	Driver.	LOZ, ORDM, Remote Control Operator.	LOZ, ATO_OB, ATO_TS.
Monitor Tram conditions	Provide UTC time	PIS, TCMS.	PIS, TCMS.	PIS, TCMS.
Monitor Tram conditions	Monitor trams	TCMS, OCC.	TLM, ORDM, Remote Control Operator, OCC.	ATO_OB, ATO_TS, TLM, OCC.
Monitor Tram conditions	Transmit periodically tram's location	PIS, OCC.	LOZ, ORDM, Remote Control Operator.	LOZ, ATO_OB, ATO_TS.
Monitor Tram conditions	Manage reporting	Driver (creates in operation), Traffic Management/Plan (receives in operation), Shunting Personnel (creates in depot), Washing Personnel (creates in depot), Operation Manager (receives in depot), Infrastructure Manager.	Remote Control Operator.	OCC, TLM, TCMS, ATO_OB, LOZ.
Monitor Tram conditions	Monitor tram unit failures	Driver, Operations Manager, TCMS, OCC.	Remote Control Operator.	OCC, TLM, TCMS, ATO_OB, PER_OB.
Monitor Tram conditions	Receive status report	Driver, Depot Manager, Infrastructure Manager, OCC.	Remote Control Operator.	OCC, TLM, TCMS, ATO_OB, PER_OB.

Monitor Tram conditions	Transmit driving anomalies	Driver, TCMS	Remote Control Operator.	OCC, TLM, TCMS, ATO_OB, PER_OB.
Perception	Detect obstacles	Driver, Shunting Personnel, Washing Personnel, Operational personnel at stations/stops, ADAS.	PER_OB	PER_OB.
Perception	Check if the surroundings (except signalling) oppose the departure	Driver.	Remote Control Operator.	PER_OB.
Perception	Detect person struck by a tram	Driver.	Remote Control Operator.	PER_OB.
Perception	Localize vehicle (track/direction/position/heading)	Driver, OCC.	LOZ, TLM, OCC.	LOZ, TLM, OCC.
Perception	Detect railway agents on or along the tracks	Driver.	Remote Control Operator.	PER_OB.
Perception	Detect vehicle or buffer stop on the same track	Driver.	Remote Control Operator.	PER_OB.
Perception	Interpret lineside signalling including vertical signs	Driver.	Remote Control Operator.	PER_OB and/or V2X_OB.
Perception	Interpret semaphore phases	Driver.	Remote Control Operator.	PER_OB and/or V2X_OB.
Tram movement	Drive tram remotely	Not available.	Remote Control Operator, ORDM, TCMS.	Remote Control Operator, ORDM, TCMS.
Tram movement	Perform shunting	Shunting Personnel, Washing Personnel, OCC.	Remote Control Operator, ORDM, TCMS.	ATO_TS, ATO_OB, TCMS.
Tram movement	Provide Brake Command for Parking Braking	Driver, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Provide acceleration	Driver, TCMS, ADAS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Provide Brake Command for Service Braking	Driver, TCMS, ADAS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Provide Brake Command for Holding Braking	Driver, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Acquire realised braking effort	Driver, TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Detect sliding	Driver, TCMS.	Automatically done by TCMS.	Automatically done by TCMS.

Tram movement	Provide Brake Command for Emergency Braking	Driver, TCMS, ADAS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Apply and release braking forces	Driver, TCMS.	Remote Control Operator, ORDM, TCMS.	ATO_OB, TCMS.
Tram movement	Check ad hoc brake release	Driver.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Process remote driving commands	Not available.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Monitor speed and distance	Driver.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Command Emergency Brake	Driver.	Remote Control Operator, ORDM, TCMS.	IPM_OB.
Tram movement	Determine maximum authorised speed	Driver, ADAS.	LOZ, IPM_OB.	LOZ, IPM_OB.
Tram movement	Supervise runaway movement	Driver.	LOZ, IPM_OB.	LOZ, IPM_OB.
Tram movement	Manage journey	Driver, Traffic Management/Plan, Route Control, OCC.	Remote Control Operator.	ATO_OB, TCMS.
Tram movement	Stop exactly at the intended location	Driver.	Remote Control Operator.	LOZ, ATO_OB, TCMS.
Tram movement	Respect JP Timing Points and Optimize the consumption	ADAS.	Remote Control Operator.	LOZ, ATO_OB, TCMS.
Tram movement	Control initial traction effort	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Calculate expected traction effort	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Regulate traction and braking effort	Automatically done by TCMS.	Automatically done by TCMS.	Automatically done by TCMS.
Tram movement	Detect that final stopping point has been reached	Driver.	Remote Control Operator.	LOZ, ATO_OB, TCMS.
Tram movement	Change running direction	Driver.	Remote Control Operator.	LOZ, ATO_OB, TCMS.
Tram movement	Manage communication exchanges with driver	Driver, Operations Manager, OCC.	OCC, Remote Control Operator.	Not available.
Tram movement	Transmit supervision orders	Driver, Operations Manager.	Operations Manager, Remote Control Operator.	Operations Manager, Remote Control Operator.
Tram movement	Transmit Emergency Stop	Driver.	Remote Control Operator, IPM_OB.	Remote Control Operator, IPM_OB.
Tram movement	Manage stopping points and passing points	OCC, Driver.	Remote Control Operator.	LOZ, ATO_OB.
Events management	Assist troubleshooting	Driver, Operations Manager, OCC.	Remote Control Operator, ORDM.	OCC, TLM, Operations Manager.

Events management	Manage tram incidents	Driver, Operations Manager, Emergency Manager (in operation), OCC.	OCC, TLM, Operations Manager.	OCC, TLM, Operations Manager.

Table 22: Comparison between the actors involved in manual operations, remote operations and autonomous operations in depo

9. CONCLUSIONS

The primary goal of this deliverable was to outline an Automatic Train Operation (ATO) architecture for tram systems. To achieve this objective, we referenced the Operational Use Cases defined in Deliverable 5.6 and the list of logical functions established by Shift2Rail X2Rail-4 for mainline applications.

We grounded the specification of this novel system in the EN 50126 V model, commencing with concept definition and conducting a preliminary risk analysis to ascertain the dangers and stipulations necessary for the system to operate at a safety level comparable to traditional trams.

The system mandates were delineated as a series of logical functions derived from Shift2Rail X2Rail-4, tailored to the tramway environment, and categorized into eight distinct groups of functions.

These logical functions were then correlated with the six Operational Use Cases from T5.6, thus formulating the requirements essential to execute each operational scenario.

Section 7 details the proposed ATO architectural framework, initiating with the explication of each functional module or actor within the architecture and specifying the packets to be transferred among them through designated interfaces to meet each logical function.

To assess the feasibility of implementing Remote or Autonomous Operations in trams, Section 8 identifies the logical functions that can be remotely or autonomously executed. It concludes that, for Remote Driving in depots, 77 of the 86 logical functions can be automated or controlled by a Remote Operator; for autonomous manoeuvres, this figure increases to 78 out of 87.

Ultimately, the research encapsulated in this deliverable lays the groundwork for the creation of an autonomous tramway prototype, which is scheduled for development in Task 10.2 of R2DATO.

REFERENCES

[1] X2Rail-4 Deliverable D3.2 – GoA3/4 Specification

[2] FP2-T5_6-D-UITP-017-02 D5.6 – Documentation of urban user cases and operational rules for automation process.

[3] Cooperative Urban Mobility Portal: https://co-ump.eu/services/

[4] 5G-MOBIX D1.2 Use Case Specification: https://www.5g-mobix.com/assets/files/5G-MOBIX-D2.1-Use-case-specifications-v1.0.pdf

ANNEX A: V2X COMMUNICATIONS FOR CCAM USE CASES

In many respects today's vehicles are already connected devices. However, in the very near future they will also interact directly with each other and with the road infrastructure. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS), which will allow road users and traffic managers to share information and use it to coordinate their actions. This cooperative element, enabled by digital connectivity between vehicles and between vehicles and transport infrastructure, is expected to significantly improve road safety, traffic efficiency and comfort of driving, by helping the driver to take the right decisions and adapt to the traffic situation.

CCAM USE CASES.

This section summarizes the CCAM use cases described in the Cooperative Urban Mobility Portal [3] and 5G-MOBIX project's Use Case specification [4]. This use cases are divided in two groups depending on the aim they follow, Operational efficiency group and safety improvement group.

Operational effiency

Green Priority (GP)

Green Priority (GP) aims to change the traffic signals status in the path of an emergency or high priority vehicle (e.g., public transport vehicles), halting conflicting traffic and allowing the vehicle right-of-way, to help reduce response times and enhance traffic safety. This service is also known as "Traffic signal priority request by designated vehicles" or "Priority Request". Different levels of priority can be applied, e.g. extension or termination of current phase to switch to the required phase. The appropriate level of green priority depends on vehicle characteristics, such as type (e.g. heavy good vehicle or emergency vehicle) or status (e.g., public transport vehicle on-time or behind schedule). The vehicles request priority for an intersection, and the traffic light controller determines in what way it can and will respond to the request.

Green Light Optimal Speed Advisory (GLOSA)

Green Light Optimal Speed Advisory (GLOSA) provides drivers an optimal speed advice when they approach a signalized intersection depending on the phase of the semaphore and the time to change phase (e.g. from green to red and vice versa). This advice may involve maintaining actual speed, slowing down, or adapting a specific speed. If a green traffic light cannot be reached in time, GLOSA may also provide time-to-green information when the vehicle is stopped at the red light. Application of GLOSA takes advantage of real-time traffic sensing and infrastructure information, which can then be communicated to a vehicle aiming to reduce fuel consumption and emissions.

Cooperative Traffic Light for VRUS (CTLVRUs)

Cooperative Traffic Light for VRUS (CTLVRUs) aims to increase the safety of vulnerable road users (i.e. pedestrians and cyclists) through warranting priority or additional crossing time (i.e., extending the green light phase or lessening the red phase) based on pedestrian characteristics (or on special conditions, such as weather). The service is also known as "Pedestrian Mobility" or "Traffic light prioritisation for designated VRUs".

Flexible Infrastructure (FI)

Flexible Infrastructure (FI) aims to interchange information about the lanes provided to the traffic users according to the time of the day. It includes solutions such as reserved lane.

In-vehicle Signage (IVS)

In-vehicle Signage (IVS) aims to provide information to the driver about the road signs (and dynamic information, e.g., local conditions warnings identified by environmental sensors). The purpose of this service is to increase the likelihood of drivers being aware of potentially dangerous conditions in case a roadside traffic sign is not noticed.

Mode & Trip Time Advice (MTTA)

Mode & Trip Time Advice (MTTA) aims to provide a traveller with an itinerary for a multimodal passenger transport journey, taking into account real-time and/ or static multimodal journey information.

Probe Vehicle Data (PVD)

Probe Vehicle Data (PVD) is data generated by vehicles. The collected traffic data can be used as input for operational traffic management (e.g., to determine the traffic speed, manage traffic flows by alerting for instance users about hot spots where the danger of accidents is higher), long term tactical/ strategic purposes (e.g. road maintenance planning) and for travelled information services. Also known as Floating Car Data (FCD).

Urban Parking Availability (UPA)

Urban Parking Availability (UPA) provides parking availability information and guidance for drivers to make informed choices about available parking places. This service aims to reduce congestion, time loss, pollution, and stress caused by cruising for parking.

Motorway Parking Availability (MPA)

Motorway Parking Availability (MPA) provides motorway parking availability information and guidance for truck drivers to make informed choices about available parking places. Existing solutions provide information about the location of truck parking areas, their capacity, equipment and facilities available on-site, security surveillance, and information about parking for lorries transporting dangerous goods. The Service provides for certain truck parking areas all over Europe the possibility to book dedicated places e.g. for sensitive or high value goods transport.

Safety improvement

Road Works Warning (RWW)

Road Works Warning (RWW) aims to inform the drivers in a timely manner about road works, restrictions, and instructions. This allows them to be better prepared for potential works downstream on the road, therefore reducing the probability of collisions.

Road Hazard Warning (RHW)

Road Hazard Warning (RHW) aims to inform the drivers in a timely manner of upcoming, and possibly dangerous events and locations. This allows drivers to be better prepared for the upcoming hazards and make necessary adjustments and manoeuvres in advance.

Signal Violation Warning (SVW)

Signal Violation Warning (SVW) aims to reduce the number and severity of collisions at signalised intersections by warning drivers who are likely (due to their speed / proximity to the intersection) to

violate a red light. Also known as the “Signal Violation / Intersection Safety” or “Red Light Violation Warning”.

Emergency Vehicle Warning (EVW)

Emergency Vehicle Warning (EVW) uses information provided by the emergency vehicle (e.g. police, fire department vehicles, ambulances, etc) to inform a driver of another vehicle about an approaching emergency vehicle even when the siren and light bar of the emergency vehicle may not yet be audible or visible. This is also known as “Emergency Vehicle Alert (EVA)”, which alerts the driver about the location and the movement of public safety vehicles responding to an incident, so the driver does not interfere with the emergency response. The service is enabled by receiving information about the location and status of nearby emergency vehicles responding to an incident.

Warning System for Pedestrian (WSP)

Warning System for Pedestrian (WSP) aims to detect risky situations (e.g. road crossing) involving pedestrians, allowing the possibility to warn vehicle drivers. Hence, the warning is based on pedestrian detection. The scope of the service can be extended to cover other Vulnerable Road Users (e.g. cyclists). The service is particularly valuable when the driver is distracted or visibility is poor. The service is also known as “Warning Systems for Vulnerable Road Users”.

Emergency Brake Light (EBL)

Emergency Brake Light (EBL) aims to avoid (fatal) rear end collisions, which can occur if a vehicle ahead suddenly brakes, especially in situations with dense traffic or with decreased visibility. The driver is warned before s/he is able to realize that the vehicle ahead is braking hard, especially if s/he does not see the vehicle directly (vehicles in between).

Cooperative Adaptive Cruise Control (CACC)

Cooperative Adaptive Cruise Control (CACC) represents an evolutionary advancement of conventional cruise control (CCC) and adaptive cruise control (ACC) by utilizing V2V communications to automatically synchronize the motion of many vehicles. While ACC uses Radar or LIDAR measurements to derive the range to the vehicle in front, CACC also takes the preceding vehicle’s acceleration into account.

Slow or Stationary Vehicle Warning (SSVW)

Slow or Stationary Vehicle Warning (SSVW) aims to inform/ alert approaching vehicles of (dangerously) immobilized, stationary or slow vehicles that impose significant risk.

Motorcycle Approaching Indication (MAI)

Motorcycle Approaching Indication (MAI) informs the driver of a vehicle that a motorcycle is approaching/passing. The scope can be extended to cover other VRUs, such as cyclists and other Powered Two Wheelers (PTW). The motorcycle could be approaching from behind or crossing at an intersection.

Blind Spot Detection (BSD)

Blind Spot Detection (BSD) aims to detect and warn the drivers about other vehicles of any type located out of sight.

AnTICIPATED COOPERATIVE COLLISION AVOIDANCE (ACCA)

Anticipated Cooperative Collision Avoidance (ACCA) aims to detect the risk of collision with other road users and inform/alter in timely manner. This use case is also known as Cooperative Collision Avoidance (CoCA). The collision avoidance includes the Longitudinal Collision Risk Warning (LCRW) for road users in the same lane and the Intersection Collision Risk Warning (ICRW) for roads coming from other lanes.

COLLECTIVE PERCEPTION ENVIRONMENT (CPE)

Collective Perception Environment (CPE) aims to enhance the environmental perception of vehicles by enabling the real-time data exchange between vehicles and perception systems located in the infrastructure.

SELECTION OF CCAM USE CASES FORM TRAMWAYS

From previously introduced list the following CCAM use cases have been analysed assigning them different interest level to improve the efficiency and the safety in the context of autonomous tram movements, both in depot in GoA4 and in operation in GoA2+ (see Table 23).

CCAM Use Case	GoA4 manoeuvres in depot	GoA2+ in operation
Operational efficiency		
Green Priority	None	Medium (already exist priority systems for tramway in the market)
Green Light Optimal Speed Advisory	None	High
Cooperative Traffic Light for VRUS	None	Medium
Flexible Infrastructure	None	None (infrastructure in tramways is not as flexible and allowing “reverse lanes” implies operational changes and safety studies)
In-vehicle Signage	None	High
Mode & Trip Time Advice	None	None (already provided by existing PIS)
Probe Vehicle Data	None	Low
Urban Parking Availability	None	None
Motorway Parking Availability	None	None
Safety improvement		
Road Works Warning	None	High

Road Hazard Warning	None	High
Signal Violation Warning	None	High
Emergency Vehicle Warning	None	High
Warning System for Pedestrian	Low (if used for depot staff)	Medium (already exist acoustic and visual systems)
Emergency Brake Light	High	High
Cooperative Adaptive Cruise Control	Medium	High
Slow or Stationary Vehicle Warning	High	High
Motorcycle Approaching Indication	None	High
Blind Spot Detection	None	High
Anticipated Cooperative Collision Avoidance	High	High
Collective Perception Environment	Medium	Medium

Table 23: Selection of interesting CCAM Use Cases for tramways

V2X MESSAGE APPLICABLE TO EACH OF CCAM USE CASES

This section introduces the V2X messages (from the ones defined by ETSI in Europe[1]) that could be used to implement each CCAM introduced in previous sections of the Annex. Table 24 summarize this relation between V2X messages and CCAM Use Cases.

		ETSI messages (EUROPE)
Operational Efficiency	GREEN PRIORITY (GP)	**SREM** and **SSEM** SREM message is used to request priority by ITS stations, whereas SSEM message is used by intersection controllers to acknowledge the requests.
	GREEN LIGHT OPTIMAL SPEED ADVISORY (GLOSA)	**SPATEM** SPATEM messages can provide advisory speed information to

[1] Note that in US and Asia the messages change although they have most of them equivalent information.

		vehicles approaching an intersection.
	COOPERATIVE TRAFFIC LIGHT FOR VRUS (CTLVRUS)	**SREM**, **SSEM** ,**VAM** and **SPATEM** SREM and SSEM messages could be used by VRUs to request priority and adapt the traffic light status to the needs of the VRUs. VAM messages transmitted by VRUs could be received by the intersection controller and by this way, without requesting directly, the status of the traffic light could be adapted. Changes applied to the traffic light would be informed in SPATEM messages.
	FLEXIBLE INFRASTRUCTURE (FI)	**MAPEM** MAPEM messages can be updated to provide flexible infrastructure topological information.
	IN-VEHICLE SIGNAGE (IVS)	**IVIM** IVIM messages provide signage information.
	MODE & TRIP TIME ADVICE (MTTA)	***POIM***[2] *POIM messages are expected to use to advice on mode and duration of travel.*
	PROBE VEHICLE DATA (PVD)	**CAM** *and* ***DENM*** CAM messages contain real time data of vehicles, while DENM messages information of events that occur on the road infrastructure. Information from both messages could be collected by infrastructure elements and stored for further processing.
	URBAN PARKING AVAILABILITY (UPA)	**MAPEM** and **PAM**

[2] POIM are new messages and ETSI is still developing its structure.

		MAPEM messages provide information about the parking slot. PAM or POIM-PA messages provide information about parking areas and its status.
	MOTORWAY PARKING AVAILABILITY (MPA)	**MAPEM** and **PAM** MAPEM messages provide information about the parking slots. PAM or POIM-PA messages provide information about parking areas and its status.
Safety	ROAD WORKS WARNING (RWW)	**DENM, IVIM, CAM** and **VAM** DENM and IVIM messages can describe a zone in which there are road works and specify restrictions and instructions. CAM messages cannot describe a working zone but it can specify that a vehicle is a road work vehicle. In the same message closed lanes due to the road works can be defined. VAM messages could be transmitted by road workers informing about its presence on the road.
	ROAD HAZARD WARNING (RHW)	**DENM** DENM messages are designed to warn about detected hazardous events.
	SIGNAL VIOLATION WARNING (SVW)	**DENM** DENM messages can be used to warn about a signal violation event.
	EMERGENCY VEHICLE WARNING (EVW)	**DENM** and **CAM** DENM messages can inform about emergency vehicles. CAM messages can contain an Emergency Container to inform

		when the vehicle itself is an emergency vehicle.
	WARNING SYSTEM FOR PEDESTRIAN (WSP)	**VAM** and **CPM** VAM messages could be transmitted by pedestrian stations to inform about their position and other relevant information. CPM messages could be sent by other stations with the perceived pedestrian data.
	EMERGENCY BRAKE LIGHT (EBL)	**CAM** and **DENM** DENM messages could be used to inform about hard brakes. CAM messages could be used to inform about a hard deceleration.
	COOPERATIVE ADAPTIVE CRUISE CONTROL (CACC)	**CAM** CAM messages can be used to know the speed, acceleration, etc., values of the vehicles in the vicinity. Also, CAMs contain the *acceleration control* data that can be used to inform that the vehicle acceleration is being controlled by cruise control. On the other hand, in the future a Platooning Container is expected to add to the actual CAM message.
	SLOW OR STATIONARY VEHICLE WARNING (SSVW)	**DENM** and **CAM** DENM messages can be used to warn about a slow or stationary vehicle. CAM messages transmit real time data, hence, slow or stationary vehicle's messages could inform other road users about its state.
	MOTORCYCLE APPROACHING INDICATION (MAI)	***CAM, VAM and CPM*** Motorcycles could transmit both CAM and VAM to advertise other road users about its presence.

		CPM messages could be used too to advertise about the presence of a motorcycle.
	BLIND SPOT DETECTION (BSD)	**CPM**, **CAM** and **VAM** Vehicles out of sight could be detected by CAMs or VAMs transmitted by these vehicles, as well as CPM messages transmitted by other vehicles that have perceived them.
	ANTICIPATED COOPERATIVE COLLISION AVOIDANCE (ACCA)	**CAM** and **DENM** CAM messages transmitted by vehicles about to collide can be used to detect possible collisions by calculating trajectories. DENM messages could be used by vehicles itself or by infrastructure elements to inform other road users about signal violation or other dangerous events that could lead to a possible collision.
	COLLECTIVE PERCEPTION ENVIRONMENT (CPE)	**CAM**, **CPM** and **VAM** CAM and VAM messages transmitted by vehicles would transmit real data of the vehicles to enhance the perception of the infrastructure systems. CPM messages indirectly would transmit real time data of vehicles perceived by vehicles, enhancing the perception of infrastructure systems.

Table 24: V2X messages applicable to each CCAM Use Case

ANNEX B: LIST OF ACTORS FOR MANUAL TRAMWAY OPERATIONS

This annex describes the list of actors present currently in the tramway operations carried out manually by operators around the world. The list of actors does not only cover the operational tasks but also activities carried out in depot:

Driver

The Driver represents a person from tramway operator that drives locally, i.e. from the driver desk of the cabin, a tram in legacy tramway operations.

Passenger

The Passenger represents the persons travelling on-board of passenger trams and embarking or disembarking at stops.

Onboard Staff

The Onboard Staff represents the persons from Operator that can be present on a tramway. Controllers in operation and testing and training personnel in special occasions.

TCMS

The Train Control Monitoring System controls and monitors various onboard subsystems installed in the Tram Unit such as brakes, traction, doors, lighting, etc.

PIS

The Passenger Information System provides various information to Passenger through visual, voice or other media. This system includes the onboard Closed Circuit Television (CCTV) system.

Physical Tram Unit

The tram unit is the physical tram and its subsystems, generally managed by TCMS and commanded by drivers, onboard staff and passengers.

Advanced Driver-Assistance System (ADAS)

The advanced drive-assistance system is a group of functions that assist driving and parking though the driver-machine interface (DMI). Depending on the project ADAS may have different functions provided to the tram driver such as obstacle detection, maximum allowed speed or speed profile for energy efficiency.

Operation and Control Centre (OCC)

The Operation and Control Centre is a system which provides to the Operator a complete visualization and control of all subsystems of the tramway system to guarantee its optimal operation controlling the fleet during operation. The Traffic Manager is places in the OCC and takes decisions from the information coming from the OCC.

Traffic Management

A member of the OCC responsible for traffic management within the commercial area of the tram network. This component plans and manages the traffic interfacing with the Driver or with the ATO-TS in driverless operations to define the stopping points, passing points and itineraries.

Infrastructure manager (IM)

The Infrastructure Manager (IM) provides the rail infrastructure, manages all relevant infrastructure data and maintains the infrastructure. The system supervises all infrastructure assets which are over the platform (e.g. track, switches, etc). Very often in tram systems, the operator and infrastructure manager are a single entity.

Planning Manager

The Planning Manager represents the person responsible for planning the routes, needed tram units and human resources for the operations.

Workshop/Maintenance manager

Workshop manager is responsible for the maintenance planning and execution of the maintenance tram unit.

Entity in Charge of Maintenance (ECM)

The Entity in Charge of Maintenance (ECM) means an entity in charge of maintenance of the tram fleet. This entity includes the Vehicle Maintenance Manager and the Vehicle Maintenance Worker. This role can be performed in-house or subcontracted, and it is dependent on the Workshop/Maintenance manager.

Operations Manager / Depot Manager

The Operations Manager represents a person responsible for the tram operation within the depot. It receives the plans from the Planning Manager and assigns the resources and sends the tram for the operation.

The Depot Manager represents a person responsible for all movements of the tram unit within the depot. It coordinates the parking, shunting and washing of tram units.

Some operators combine depot manager and operations manager, being both part of the tramway operator.

Tram Preparation Staff

The Tram preparation staff represents the personnel from Operator/Tram Maintenance who intervene when a tram is at a standstill. This entity includes staff with driver skills, the Shunting Yard Worker and the Clean Worker. This actor executes orders from the Operations/Depot Manager.

Shunting Personnel

The Shunting personnel is part of the Tram preparation Staff which is responsible for shunting operations. This actor executes the orders from the Operations/Depot Manager.

Washing Personnel

The Washing personnel is part of the Tram preparation Staff which is responsible for tram washing operations. This actor executes the orders from the Operations/Depot Manager.

Safety and Technical Department

The Safety and Technical Department is responsible for supervision of all the technical and safety aspects of the tram fleet and traffic which affect the safe and optimal operation. They are responsible for maintenance procedures and plans definition, which affect to both, the trams in depot and in operation.

Operational personnel at stations/stops in abnormal situations

Operational personnel at stations/stops who supports the management in the case of abnormal situations. Depending on the operator it could belong to the tram operator or to a third company.

Emergency Operation Manager

The Emergency Manager carries-out non-automated emergency functions which require human actions in tram operation. All problems detected in the tram unit are transmitted from the driver to the OCC and the Emergency Operation Manager decides the actions to take, for example evacuate the unit.

Emergency Workshop staff

The Emergency Manager carries-out non-automated emergency functions which require human actions in tram workshop. It takes care of rescuing tram and bring it to the depot and substitution of the tram unit.

Light Signal

The Light Signal is an optical indicator that transmits information to tram drivers.

Energy Manager

The Energy Manager manages the electrical power distribution along the track and catenaries.

Route Control

This logical component controls the setting and locking of the routes. In operation the driver is the one to change track switches to follow the preprogrammed route. In depot, some operators do have automatic and centralized route controllers.