Rail to Digital automated up to autonomous train operation

D41.1 – Collection of test cases and validation criteria

Collection of test cases and validation criteria for remote driving of tramways demonstrator.

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REPORT CONTRIBUTORS

Name	Company	Details of Contribution
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Daria Kuzmina	UITP	Review
Nacho Celaya Vela	CAF	Collection of test cases for demonstrators in Oslo and operational ruls to us cases to test cases matrix. Definition of accept and validatio criteria.

EXECUTIVE SUMMARY

- Context and objectives:

  The selected test cases and validation criteria provide a test plan and procedures to validate remote control of the tramway during Oslo demonstrator in WP41.

  Cross matrix between operational rules, use cases, test cases and safety criteria secures validation of expected outcomes and gives overview over operational use cases covered in the demonstrator.

  The selection of the high-level use cases in D40.1 structures test cases for demonstrator and are further developed in this deliverable.

  The selection is created by Sporveien Trikken and CAF, responsible for execution of demonstrator in Oslo and reviewed by UITP. Test case reflects and are limited to technical possibilities given by modifications on the vehicles for demonstration.

- Scientific/Technical approach or methodology:

  The startpoint for the work was to collect and review routines and procedures that are used to manage tramway operations in Oslo. These documents describe and all rules, requirements and prequisitions for tramway operations at Sporveien Trikken in Oslo. [1]

  The high-level operational use cases from deliverable D40.1 were input to this task, elaborated further and adjusted to technical possibilities and TLR7[1] for remotely controlled tramways.

  Deliverable form WP 5.6 was also used as referance for additional evaluation of test cases for WP41.

  The same methodology and aproach shall be used for selection of test cases for autonomous movements with TRL6 in the WP42.

  WP 6.6 deliverable was used when evaluating technological readiness for remote control demonstrator and selecting accept criteria for WP 41.

  Testing and validation of the technical solutions for remote driving was devided to three main groups (elaborated later in the deliverable)

  - Auxiliary curcuits tests
  - Statical tests
  - Dynamical tests

- Main (scientific) findings/conclusions from the deliverable:

  It has been concluded that technical solutions and existing technological progress allows us to prepare relavant test cases and testing plan for demonstrator in WP41.

- Deliverable status - further R&I is needed.

  Deliverable fully covers project scope given for this task. Many technical solutions, however, may and will be subject of further research developement in the future projects (e.g.,. R2DATO phase 2).

[1] https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

Progress and development of new IT solutions and especially AI can open new possibility for autonomisation of tramway opererations.

Although, selection of test case for commercial areas is not part of this deliverable and further analysis and research needs to be done, many of the test cases for non-commercial areas are relevant for further tests in combined traffic and commercial operations.

ABBREVIATIONS AND ACRONYMS

AC	Alternative Current
APS	Auxiliary power supply
ATO	Automatic Train Operation
AUTO	Automatic
BCU	Brake control unit
CAF	Construcciones y Auxiliar de Ferrocarriles
CAN	CAN Standard Bus
CCTV	Closed Circuit Television
CCU	Central control unit
CERES	CAF Remote Control Centre
COMMS	Communication
DATO	Digital Automated up to autonomous Train Operation
DC	Direct Current
DCM	Desk Control Module
DCU	Door control unit
EED	Emergency egress device
GMS	Global System for Mobile Communications
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HMI	Human Machine Interface
HSCB	High Speed Circuit Braker
HUD	Head up display
HVAC	Heating Ventilation and Air Conditioning
IPM	Incident Prevention Module
LED	Light Emitting Diode
LOZ	Localization System
MCB	Magnetic Circuit Breaker
MAX	Maximum

MED	Medium
MIN	Minimum
MQTT	Message Queuing Telemetry Transport
OR	Operation Rule
R2DATO	Rail to Digital Automated up to autonomous Train Operation
PA	Passanger Alarm
PAS	Passanger Address System
PER	Perception System
PIS	Passanger Information System
PLC	Programmable Logic Controller
PPP	Pis Pas Pa System
PRM	Person with Reduced Mobility
PTT	Push to Talk
SL18	Tramway type use in Olso and for demonstartor
SS1	Safety Switch 1
SS2	Safety Switch 2
STR	Sporveien Trikken AS
TCMS	Train Control and Monitoring System
TCU	Traction control unit
TL	Train Line
TRL	Technology readiness level
UITP	International Association of Public Transport
UC	Use Case
V2X	Vehicle to (2) Everything

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2 INTRODUCTION

Deliverable 41.1 **Collection of test cases and validation criteria** is part of WP 41 **Remote Driving and Telecommand Demonstrator**. WP41 is part of the demonstrator cluster and urban light trains WP, aiming at selection and analysis of specific operational test cases and its development. The deliverable defines test scenarios and cases accept criteria to validate test results. Definition of detailed KPIs is also included in this task.

The deliverable depicts main activities and a test plan for the task 41.3 **Demonstration phase.** Two trams (model SL18 of the Sporveien fleet) are to be modified in the CAF factory in Zaragoza. Modified vehicles and new functionalities will be pre-tested in factory.

Selection and analysis of specific operational use cases and their transformation to test cases for demonstration, is main focus of this deliverable.

Test cases for the demonstrator in Oslo are carefully selected for testing of functional abilities of remotely controlled trams and demonstrating telecommand[2] up to TRL7 in WP 41.

Main contribution to this task within R2DATO is coming from WP 6.6 Specification of ATO functions for trams.

In order to align definitions across the deliverables, a short extract from D40.1 explaining definitions of operational rules, operational use cases, future operational use cases, technical use cases and test cases is presented below.

Operational rules for non-commercial areas (an area within the tram network restricted to public access, primarily used for fleet maintenance and parking - depots) regulate operations of the trams in regard of parking, and stabling of the vehicles out of operations, pre-start control and verification of the vehicles before operation, all movements within defined areas – shunting, transfer to workshops, wheel lathe, washing line and parking again. The operational rules in Sporveien Trikken in Oslo consist of a set of procedures, regulations, routines, and requirements both for operations, vehicles, and staff. Based on the list of operational rules operational use cases were identified.

Operational use cases had an aim to summon operational rules of the same nature into the operation rules clusters in existing operational environment. (e.g., there are many signs and signals that are described in operational regulations, but in operational use case all sums up in “detect traffic sign or signal and take required action”)

Future operational use cases are taking starting point from the analysis of operation rules and existing operational use cases. They cover not only existing operational environment, but also possibilities and requirements originating from remote control / driving and autonomous movements of the trams in the non-commercial areas. The list represents a database of operational use cases that need to be matched with technical use cases.

Technical use cases are based on the requirements and expectations coming from operational use cases for remote driving and autonomous movements and are created in order to identify areas of possible deployment of automatization that possible also to be demonstrated in R2DATO. They include remote driving operations and vehicle control to autonomous movements of the test vehicles in non-commercial areas at Sporveien Trikken in Oslo.

[2] Telecomand in this context is meant as data exchange without any active controll of the vehicle

Test cases are selected operational and technical use cases to be demonstrated along the project lifetime. This basically means testing and validation of technological solutions with aim to further design, modify, and integrate appropriated systems. Main focus is put on further development of autonomous driving functions.

Final product of this deliverable is carefully selected list of test cases for demonstrator in WP 41. Operational rules – Use cases – Safety requirements and test cases matrix, providing interface and correlation is part of this deliverable.

Technical limitations and technology development status in the time of the demonstrator is what limit automatization of some operational rules and use cases. This results in not all operational use cases being transferred to test cases.

Sporveien Trikken depot at Holtet Oslo (the main demonstrator area with outdoor tracks suitable for testing) and Sporveien Trikken depot at Grefsen, Oslo (a back up demonstrator area with indoor tracks suitable for testing) have been chosen for the demonstrator locations. This is also taken into the consideration for selection of the test cases.

3 REMOTE DRIVING DEMONSTRATION

3.1 TESTING STRATEGY AND TEST CASES

The main objective of WP41 is to validate remote command functions, both static and dynamic, from a remote-control center. This functionality brings a wide range of possibilities for improving operation to the final user.

The train establishes a communication tunnel with the remote command center, allowing sending and receiving information on two different layers:

On the one hand, there is the communication layer dedicated to video streaming. Each cabin is equipped with two cameras that stream a low latency video from the train to the remote-control center, with images properly identified and marked. The remote-control center is able to send commands to prioritize the image from a specific camera or record data and commands.

On the other hand, there is a communication layer aimed at sending and receiving tram control commands. These commands replace the local driver's command, becoming a new input source for the existing functions and sub-systems on the train. Some examples of these remote commands may include:

- Pantograph raise and lower command.
- Main circuit breaker open and close command.
- Emergency lights activation command.
- Acoustic warning command.
- Traction demand command.
- Brake demand command.
- Emergency brake command.

As the project is based on retrofitting two units from an existing fleet to perform the previously described functions, there are two perspectives for vehicle validation:

1. Integration validation of the new equipment and non-regression.
2. Functional validation of the newly integrated functions.

The first perspective has been addressed by focusing on the modification in the vehicle installation. A test case called *Auxiliary Circuits Test* has been designed to validate this integration and ensure that it does not have a negative impact on previously functions and sub-systems tested on the vehicle.

The functional validation of the new integrated functions has been separated into two distinct test cases: a *Static Functional Tes*t and a *Dynamic Functional Test*.

From both operational and RAMS (Reliability, Availability, Maintainability, and Safety) analysis perspective, there is a gap between static and dynamic remote commands for obvious reasons. For this reason, it has been decided to approach their validation separately.

3.1.1 Auxiliary Circuits Test

The purpose of this test group is to check the correct operation and functionality of the electrical circuits implemented in test units for the R2DATO project.

This is to check both the circuits and part of the PLC program (TCMS). The proposed actions should give the results described, thus checking the wiring of the circuits, including TCMS inputs and outputs and part of the software of the PLC.

Scope of this testing includes electrical auxiliaries and safety supervision.

3.1.2 Static Functional Test

The purpose of this test is to check the correct operation and functionality of the remote control of a test unit in static position and driving system implemented in test units for the R2DATO project.

This is to check the correct interaction between part of the PLC program (TCMS) and the CERES. The proposed actions should give the results described, thus checking that CERES actions performed correctly, including TCMS inputs and outputs and part of the software of the PLC.

No movements of the test tramway during this test sequence.

3.1.3 Dynamic Functional Test

The purpose of this test is to check the correct operation and functionality of the remote control under movement of a test unit and driving systems implemented in test units for the R2DATO project.

This is to check the correct interaction between part of the PLC program (TCMS) and the CERES. The proposed actions should give the results described, thus checking that CERES actions performed correctly, including TCMS inputs and outputs and part of the software of the PLC.

Tramway shall be in movements during this test sequence.

3.2 SELECTED TEST CASES TEST PROTOCOLS AND ACCEPT CRITERIA

3.2.1 Auxiliary circuits Test

3.2.1.1 Selected test cases for auxiliary circuits test

The following are the list of test cases covered in the static test procedure:

- Verification of driver's safety device in mode 0 – all installation for perception and remote control are switched off
- Verification of driver's safety device in mode 1 – only installation for perception are switched on
- Verification of driver's safety device in mode 1 – all installation for perception and remote control are switched on
- Tram off - Remote wake up test
- Remote control commands test
- Box fan test
- Remote driving loop test
- Remote active cabin test
- Remote driving commands test
- MCB monitoring

The test is OK if all steps above are carried out correctly.

3.2.1.2 Operational use cases covered by auxiliary circuits test

Operational use cases covered by Auxiliary circuits Factory Type Test [1]:

- Establishing connections
- Initiate data communication
- Perform video streaming
- Identify position of the vehicle in the depot
- Activating vehicle
- Connect to HV
- Control of alarms on TCMS-HMI monitors or alarm lamps on driver desk
- Break check
- MCB check

3.2.2 Static Functional Test

3.2.2.1 Selected test cases for static functional test

The following are the list of test cases (base on operational use cases) covered in the static test procedure:

- Start up the tram locally.
- Start-up CERES system. (CERES)
- Check connection status. (CERES)
- Connect to the tram. (CERES)
- View cab cameras. (CERES)
- Take remote control. (CERES)
- Active cab camera is shown. (CERES)
- Remote command – High Voltage connection. (CERES)
- Remote command – Bell. (CERES)
- Remote command – Horn. (CERES)
- Check tramway state machine transition to new modes.
- Turn off the tram prepared to be remotely turned on. (CERES)
- Turn on the tram remotely. (CERES)
- Turn off the tram but not prepared to be remotely turned on (CERES)

The test is OK if all steps above are carried out correctly.

3.2.2.2 Operational use cases covered by satic functional test [1]:

- Activate turn key (manually)
- Service switch control
- Vehicle self-test
- Pantograph positioning (up and down)
- Control of alarms on TCMS-HMI monitors or alarm lamps on driver desk
- Brakes activation
- Put driving control to emergency-brake position
- Activate and deactivate “Deadman” function
- Lights functionality control
- Mirror camera control
- Visibility control

3.2.3 Dynamic Functional Test

3.2.3.1 Selected test cases for dynamic functional test

The following are the list of test cases (base on operational use cases) covered in the dynamic test procedure:

- Check tramway state machine transition to remote driving
- Service brake test
- Max. Service Brake test
- Emergency Brake test
- Drive the tram remotely from some meters.
- Turn off the tram but not prepared to be remotely turned on

The test is OK if all steps above are carried out correctly.

3.2.3.2 Operational use cases covered by dynamic functional test [1]:

- Establishing connections
- Initiate data communication
- Perform video streaming
- Identify position of the vehicle in the depot
- Activating vehicle
- Check proper visibility
- Check track for any obstacles for driving (visual). No object can cross yellow lines marking driving profile
- Acoustic signal before driving
- Acceleration and deceleration
- Flashlights on and off
- Detection
    - Detect signal in the depot (red or green light)
    - Detect track number signal (when entering parking area)
    - Detect obstacle (object in the or near track)
    - Detect yellow “zic-zac” line (Track cannot be entered if another vehicle is parked in the next track)
    - Detect middle point sign
    - Detect gate / door to workshop, commissioning hall, lathe hall and washing hall
    - Detect stop marking in the depot (blue or yellow parking marks)
    - Detect another vehicle in the same track
- Weather issues – check visibility under different kinds of weather and light
- Change cabin and direction of driving
- Stop for parking
- Terminate data communication
- Finish connection with the tram
- Switch off communication to stand by or completely
- Secure vehicle from unauthorized driving

3.3 KPI

To assess the validity of the solution, it is essential to highlight that there are two perspectives to address.

3.3.1 KPIs for Non-Innovative Developments:

On one hand, there are go-no-go validation tests. For example, everything related to the integration of new equipment, electrical installation, and non-regression, which can be easily quantified within the protocols to be carried out in the project.

3.3.2 KPIs for Innovative Developments:

However, the goal of the project itself is not only to develop but also to optimize and make the proposed solution reliable. In this regard, two categories of KPIs can be distinguished: qualitative, related to user experience, solution validity, etc., and quantitative, related to the parameterization of the subsystems involved in the development or the measurable impact they generate for the end user.

Thus, an initial list has been compiled that will be updated and discussed throughout the project to assess the maturity and satisfaction level of the proposed solution. This list can be applied to each previously described test case but also serves as a guide for the future development of new cases.

Table 1: KPI

KPI	Type	Explanation	Measurement criteria
System integration without impact on existing vehicle	Technical	Evaluate if the protocols proposed for validating the installation in an existing vehicle and its non-regression are successful.	Yes / No
Solution quality for the remote operator	User Experience	Rating of the solution's quality for the remote operator	1...5
Image quality	Technical	Rating of the image quality	1...5
Image latency	Technical	Latency in milliseconds	ms
System availability	Technical	Failure rate	Failure rate
Economic impact on annual operation	Economic	Impact in thousands of euros	k€

3.4 DEMONSTRATOR LOCATION

3.4.1 Holtet depot

Holtet outdoor tracks is an important advantage of the testing and demonstrating of remote driving. Outdoors environment gives a possibility to test and validate equipment under various weather, light and external conditions. This is crucial for validating of the perception sensors and equipment.

Holtet depot is not occupied during the daytime more or less from 6 am to 6 pm and gives a possibility for multiple test scenarios and is equipped with advanced signalling system.

The location of the CERES, commercial name for the Remote Operating Centre developed by CAF under R2DATO, is also on Holtet in existing operation manager office. Office has good IT network and connections and real view to tracks dedicated to the demonstrator. A small workshop at the depot shall be used both for parking and minor repairs or installations.

Figure 1: Tracks intended for demonstration.

4 CONCLUSIONS

Deliverable covers test cases and test and driving plan for demonstrator in WP41. Test cases are based on operational and technical use cases selected from tramways operational rules in Oslo.

Selection of the test cases reflects today's status of technical solutions and possibilities. Not all operational cases can be automatized for remote driving operations due to technological limitations.

We expect to update and further develop test plan as we progress along the project and evaluate outcomes from the demonstrator.

It might be necessary to investigate in possibility to change operational rules for tramway operations (in Oslo) in order to increase level of automatization and implementation of remote control solutions in the tramways operation.

Short summary of the deliverable:

- Objective to create a list of test cases, outline a test plan, asses testing site and give bases to risk analysis for the demonstrator is fully accomplished;

- List of test cases also gives a good overview over technical possibilities of remote driving and contributes to new approach to creating operation rules in technologically new environment;
- Spliting testing into three groups contributes to logical test sequences and step by step validation of technical solutions;

REFERENCES

[1] Operational rules and operational use cases for non-commercial areas