Rail to Digital automated up to autonomous train operation

D38.3 – Results of remotely monitored stabling and bringing a train to the station with remote monitoring

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EXECUTIVE SUMMARY

This document describes the results of a demonstrator combining the technologies of remote train operations (RTO) with ATO-GoA2 to perform stabling operations in a real-world environment in the Netherlands. The combination of RTO with ATO-GoA2 is a new concept (referred to as 'RTO-GoA2') that has not previously been investigated or tested in ERJU or Shift2Rail.

The study identifies a number of use cases describing the interactions between the remote driver from the ROC, with the ATO-GoA2 system onboard of the train, including specific elements related to operating ATO on the Dutch ATB signalling. The interactions described in the use-cases form the basis for the technical solution that was developed, as well as the methodology for the field study in which the technology was applied in a real-world setting.

A technical solution has been developed based on the previously tested [1] solution for remote driving, which was upgraded to include user interfaces and control mechanisms to operate the ATO-GoA2 solution on board of the same trainset. This upgrade consists of three main features added to the ROC's steering desk: (1) a physical button for (dis)engaging ATO, (2) a keypad for confirming or correcting the signal aspect and (3) a user interface showing the ATO-DMI. All features were integrated into the communication interface between the ROC and the RTO-OB unit, without any noticeable impact on latency and system performance compared to the RTO-standalone solution. The developed technical solution was integrated by CAF into an existing Sprinter New Generation (SNG) regional trainset of NS. This trainset was already equipped with a prototype ATO-GoA2 solution that has previously been tested by CAF and NS over both ETCS and ATB. To support the ATO-GoA2 operations, features were implemented for signal perception, positioning and the integration with the ETCS-OB.

A study was performed in which experienced remote drivers were performing stabling operations using the RTO-GoA2 solution over the commercial line between Hengelo and Enschede in mixed-traffic at operational speeds of up to 125km/h. The drivers performed the different use-cases to investigate the technical feasibility and potential challenges. In general, the results indicate that the technical system was performing well without any noticeable difference in latency compared to the RTO base solution. The drivers were able to perform all of the mentioned use-cases when operating in optimal track and weather conditions, providing first indications on the technical feasibility of the RTO-GoA1 concept. While it was technically possible to perform all tasks, difficulties were observed with the remote driver's ability to provide feedback on the proposed signal aspect of the perception system, this is caused by the limitations of the installed perception sensors.

ABBREVIATIONS AND ACRONYMS

ADM	Automatic Driving Module
AI	Artificial Intelligence
ATB	Automatische Treinbeïnvloeding (Automatic Train Protection)
ATO	Automatic Train Operation
ATO-OB	Automatic Train Operation On Board
ATO-TS	Automatic Train Operation Trackside
ATP	Automatic Train Protection
CBG	Centrally Controlled Area
CNN	Convolutional Neural Network
DM	Digital Map
DMI	Driver Machine Interface
ES	Enschede
ETCS	European Train Control System
GoA	Grade of Automation
HGL	Hengelo
HMI	Human Machine Interaction
LZ	Localization System
MRSP	Most Restrictive Speed Profile
OB	On Board
PER	Perception System
R2DATO	Rail to Digital automated up to autonomous train operation
RD	Remote Driver
RD-OB	Remote Driving On Board
REP	Repository
RGB	Red Green Blue
ROC	Remote Operation Centre
RTO	Remote Train Operation
SCV	Signal Converter
SD	Safety Driver
SNG	Sprinter New Generation
STM-ATB	Specific Transition Module – Automatic Train Protection
TCMS	Train Control and Management System

TE	Technical Enabler
TMS	Traffic Management System
TP	Train Protection
TRL	Technical Readiness Level
TRN	Train Running Number
TTC	TreinTestCentrum

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1 INTRODUCTION

Task 38.3 "Stabling a train and bringing a train to the station with remote supervision (GoA2)" is part of R2DATO WP38 titled "Automatic Stabling, Shunting and Non-commercial runs Demonstrator". The aim of this work package is to test the different technical enablers for automatic stabling, shunting and non-commercial runs. This deliverable discusses the research that has been done in combining the technology of Remote Train Operation (RTO) with ATO-GoA2, allowing a Remote Driver (RD) to supervise ATO-GoA2 shunting and stabling movements from a remote location.

The combination of RTO and ATO-GoA2 is a new concept that has not previously been studied within the ERJU or Shift2Rail context, this demonstrator is the first application combining the two systems in a real-world environment. It will be referred to in this document as RTO-GoA2. The RTO-GoA2 concept builds on the RTO concept by adding ATO GoA2 systems to the train which support the RD in their driving tasks. The RD is controlling the train remotely, and is supported by the ATO-Goa2 operation which takes over traction, coasting, and braking functions.

The aim of this study is to identify the technical feasibility of the RTO-GoA2 concept, driving between Hengelo and Enschede using the prototype solution, as well as identifying how the RD experiences the differences when monitoring the ATO system compared to driving the train remotely in RTO GoA1. This is done by performing use-cases that are first identified and then performed and analysed as part of this study. The combination of ATO and RTO provides a first operational insight in the concept of remote supervision; an important topic in the future for handling degraded mode scenarios under ATO-GoA4. Due to the unavailability of ETCS on Dutch shunting yards, the tests were performed on lineside signalling (ATB-EG).

1.1 PROJECT RELATIONS

Internal WP-relations

The RTO-GoA2 technical solution applied in this study applies is a result of combining functionalities from an RTO-system, with the technology of ATO-GoA2. Within another deliverable, the base remote driving solution and the corresponding demonstrator are described:

- Task 38.2 *"Results of GoA1 remote controlled stabling and bringing a train to the station".*

While the technology of this deliverable is restricted to ATO-GoA2, the ATO-base components of this solution form the basis for the ATO-GoA4 tests as described in:

- Task 38.4 *"GoA4 stabling and shunting, including non-commercial runs, with Remote Control Centre as backup".*

Due to the experimental nature of the technology applied in this task, it was specifically decided not to relate to the work of Task 38.1 "*Training of involved staff*", which focuses on the concept of Remote Driving as a standalone solution. Nor does it relate to Task 38.9 "*Monitoring, analysis and reporting*", which will focus on Remote Driving and ATO-GoA4 as standalone solutions.

R2DATO relations

While the base functionality of Remote Driving has been covered in many R2DATO and Shift2Rail tasks, the combination with ATO-GoA2 has not previously been discussed. Therefore, there are no relevant use-cases or requirements. Therefore, the first step of this deliverable is aimed at establishing relevant use-cases for proving the technical feasibility.

1.2 OBJECTIVES

- The purpose of this study is to perform the first ever field trial combining the technologies of remote driving with ATO-GoA2 to investigate the technical feasibility of this concept, along with the potential benefits and complications.
- Due to the early stage of the technology the focus will be on evaluating high-level technical feasibility by performing simple use-cases. Degraded modes and complex operating conditions are not in scope, and the tests are limited to a small number of test runs.
- A first attempt is made at investigating the human experiences and desirability of the RTO-GoA2 concept, but it will only scratch the surface with a small number of users and no involvement of human factors experts.
- The performance of the stand-alone RTO solution (i.e. latency) is not in scope of this study. These topics are exclusive to D38.2.
- The performance of the ATO-solution (i.e. reliability, signal detection) is not in scope of this study. These topics are exclusive to D38.4.
- The tasks of (un)coupling have not been included; this functionality is not part of ATO-GoA2 and should be performed either by the remote driver (RTO-GoA1) or automatically (ATO-GoA4).
- Driving over non-centrally controlled tracks with or with manual switches has also not been part of the scope in this study due to the lack of infrastructure data, ATP and timetable input.

2 RESEARCH METHODOLOGY

The design of this study is based on applying the ATO-GoA2 combined with remote driving technology in a real-world environment and evaluating the ability of the RD in working with the technology.

To assess the ability of the end user in working with the technology, the relevant use-cases for proving the technical feasibility have to be established. During the test runs, the use-cases, such as correcting ATO's signal recognition if necessary, or stopping the train in an emergency situation, are executed. Additionally, the study investigates how the remote driver experiences the differences between supervising the ATO system and operating the train remotely under RTO GoA1 conditions. To gather this information, an observer at the Remote Operation Centre (ROC) conducted an interview with the remote driver.

The decision has been made to focus on demonstrating basic functionalities needed for shunting at each Grade of Automation, the "happy flow" use cases. This means that scenarios in which the Remote Driver (RD) and/or system are intentionally confronted with degraded situations (e.g., infrastructure malfunctions, train system failures, or emergency situations) are not included.

In addition to documenting the use cases and conducting the interview with the remote driver, an observer stationed on the train carried out detailed observations during each test run. These notes provided real-time insights into the operational context and any challenges encountered. The collected data included:

- **Train Running Number (TRN):** Unique identification for each train journey to track and cross-reference observations.
- **Route Driven:** Specification of the exact route taken during each test to identify location-specific factors or variances.
- **Weather Conditions:** Recording weather data is critical since environmental factors can influence train operations and test outcomes.
- **Number of Interventions:** Number of manual or system interventions required during the test, providing a metric for automation reliability and safety implications.
- **Technical Difficulties:** Documentation of any faults, system errors, or malfunctions encountered that could be of impact.
- **Event Documentation:** Comprehensive logs of all notable occurrences during the test run, including software updates, interruptions by external factors, unexpected stops, and significant changes in weather conditions.

Parallel to the onboard observations, an observer in the ROC made detailed notes during the test runs. These observers focused on the following factors:

- **Number of Interventions:** Number of manual or system interventions required during the test, providing a metric for automation reliability and safety implications.
- **Technical Difficulties**: Documentation of any faults, system errors, or malfunctions encountered that could be of impact.
- **Comments** or concerns that were made by the remote driver related to their remote driving experience and performance.

2.1 Test Environment

The research as described in this deliverable take place in two physical environments, which are the ROC in Utrecht and the railway environment between Hengelo and Enschede central stations. The locations of the test environments are displayed in Figure 1. This chapter further describes the characteristics related to the test environments.

Figure 1: The location of the ROC and test environment.

2.1.1 Remote Operation Centre

The ROC is located in the head office of NS (Laan van Puntenburg) and is situated in a dedicated room in the IT/OT test laboratory of NS. This room of approximately 35 m² features customizable lighting conditions (i.e. dimming in multiple sectors) and is protected using a badge reader only allowing selected employees to enter. All windows were blocked using opaque foil to prevent interference with passing office workers. Due to the location of the ROC being in the middle of the office building, there are no indications of outside (day)light and weather conditions.

Situated in the ROC is the steering desk, visible in Figure 2, that is used to operate the train remotely. It features control elements similar to the onboard controls and a livestream to the train. Furthermore, the ROC also has multiple working desks and computer setups that are used by the research leader during the experiment.

Figure 2: The ROC Steering Desk

2.1.2 Railway Environment Hengelo-Enschede

During this study, the train is driving on the railway segment of Hengelo-Enschede, located at a 116km distance from the ROC in Utrecht. Both the Hengelo and Enschede areas feature a mainline station with at least four platforms, and an adjacent shunting yard.

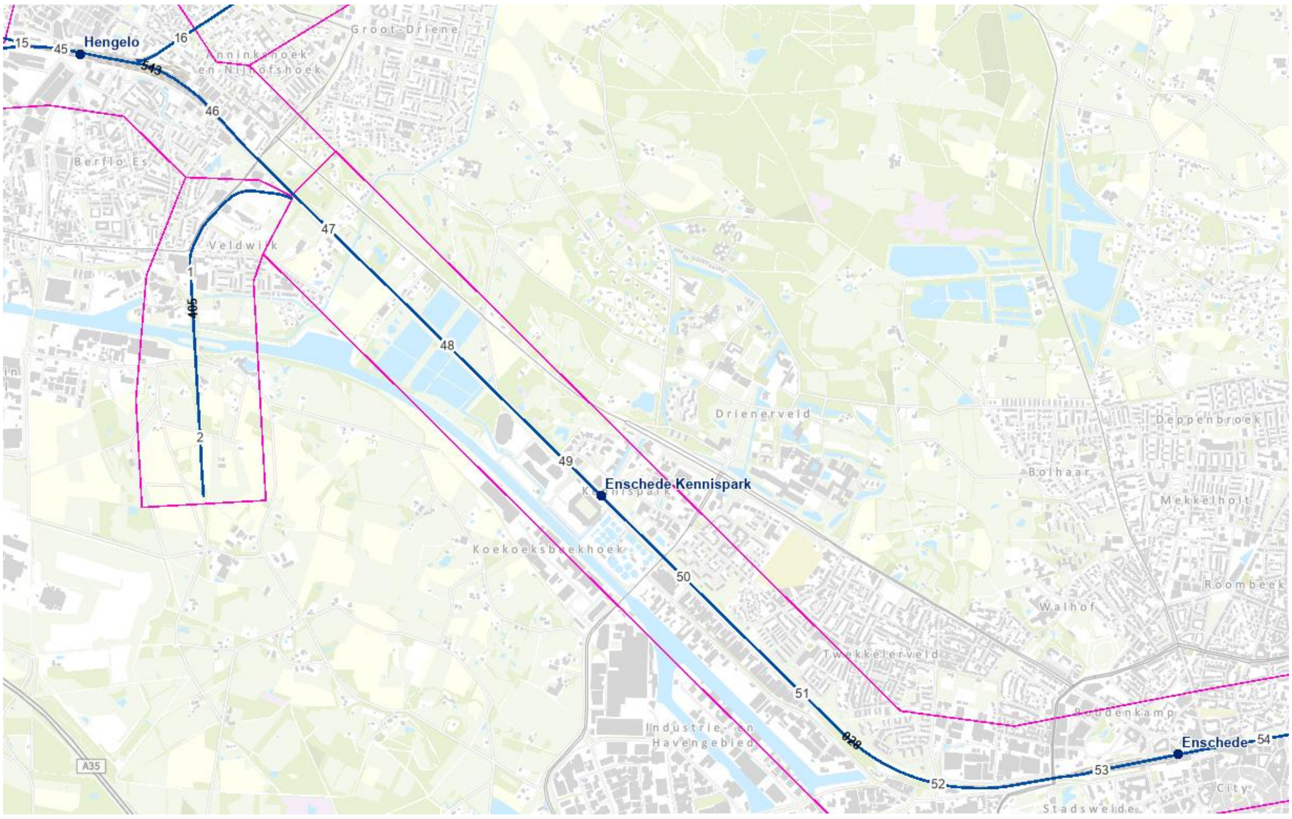

Figure 3: Segment Hengelo-Enschede (BasisBeheerKaart ProRail)

The tests during this study were conducted on tracks that are equipped with Dutch lineside signalling (ATB “Verbeterde Versie”). There are no shunting yards in the Netherlands equipped with ETCS, hence the need to perform this study over lineside signalling. This study was entirely performed over centrally controlled tracks with automated switches, located in the Centrally Controlled Area (CBG). Figure 4 shows the station and shunting yard of Hengelo. The most common position for the train to be situated at when starting or ending the remote journey is shown as “Train”, this position is also shown in Figure 4.

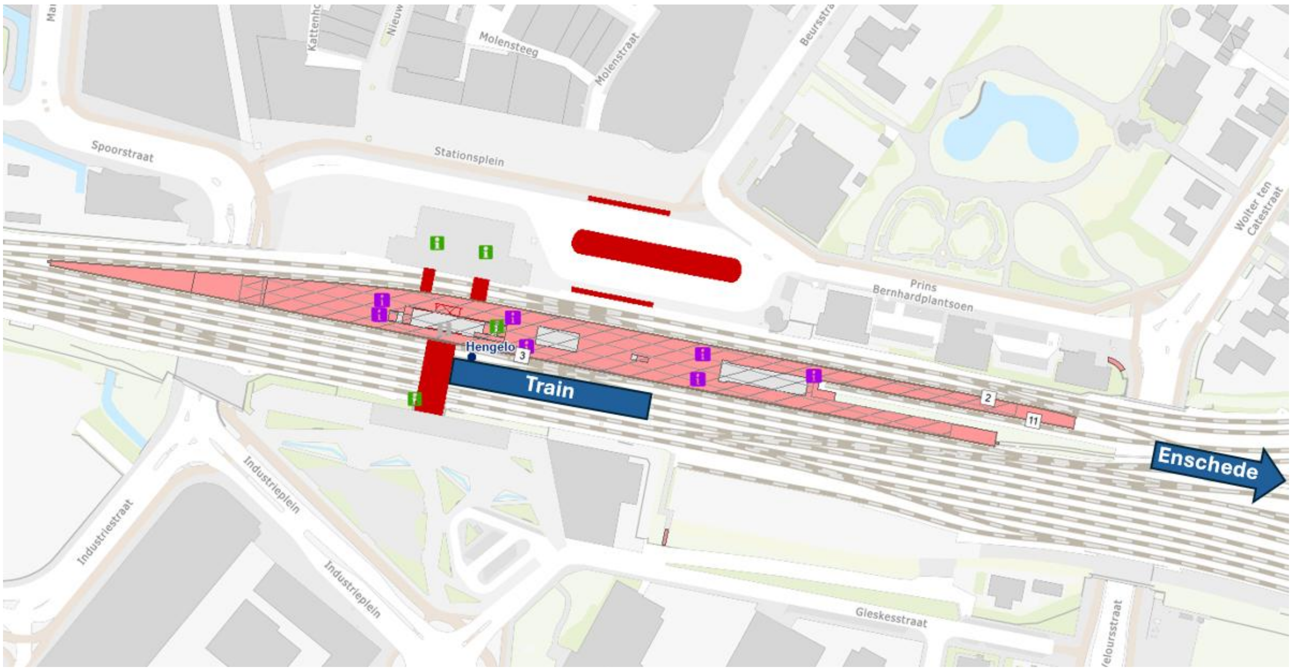

Figure 4: Station area of Hengelo (BasisBeheerKaart ProRail)

Figure 5: The SNG3002 located alongside Hengelo Station (De-Amerfoortse-spotter)

The area between Hengelo and Enschede consists of an 8 km railway segment, with double tracks and one intermittent station Enschede Kennispark. This segment has an operating speed of 125 km/h, with gradual speed reductions on both the Hengelo and Enschede approach. There are three protected level crossings between the stations of Hengelo and Kennispark. An overview of the track between Hengelo and Enschede can be found in Figure 3.

Enschede is an end-station, featuring buffer stops at the end of both the passenger and shunting tracks. The shunting tracks are located alongside the station so shunting operations require changing direction at a dedicated shunting track, this track also contains the washing installation. All of the passenger and shunting yard tracks can be reached when approaching from Hengelo. An overview of the Enschede area can be found in Figure 6.

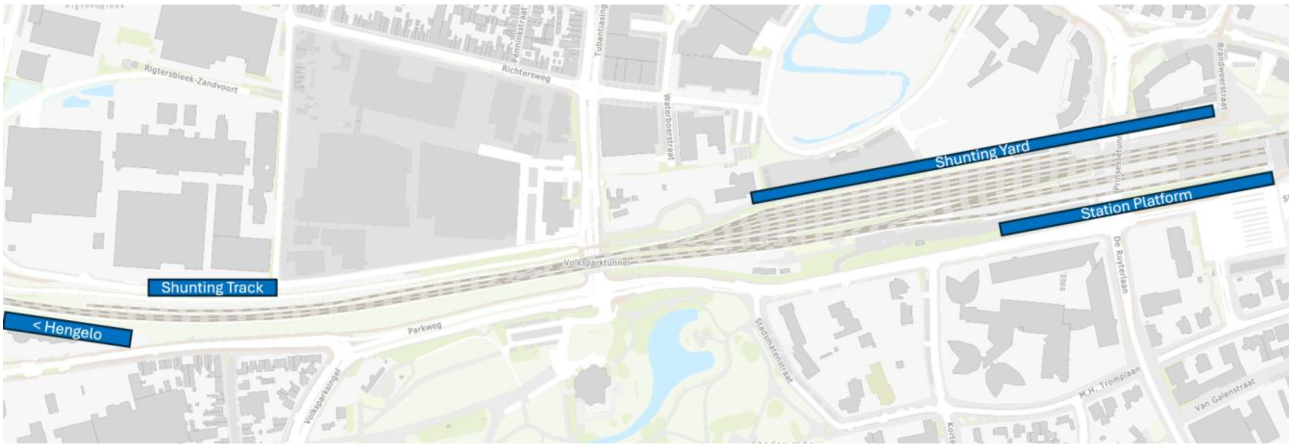

Figure 6: Enschede Station area (BasisBeheerKaart ProRail)

2.2 Research Timetable Design

This study is performed on a high-density railway line used for regional, intercity, international and freight operations. The planned traffic on this line is treated with a higher priority compared to the research runs; it is therefore not possible to have a consistent timetable for all test days. The run duration, intervals and number of runs therefore differ between the research days.

The generic timetable design tried to perform mainly stabling runs, using a basic timetable template of:

1. Depart from Hengelo shunting track.
2. Short stop at Enschede Kennispark station.
3. Arrive at Enschede station.
4. Change driving direction (min 10 minutes).
5. Depart from Enschede station.
6. Short stop at Enschede Kennispark station.
7. Arrive at Hengelo shunting track.

An example timetable is shown in Figure 7, featuring two runs from Hengelo (HGL) to Enschede (ES) and vice-versa. The total journey time is between 9 to 13 minutes, all runs were performed at the maximum operating speed (up to 125km/h).

Most of the tests were performed during daytime, either in an early (i.e. 9-15) or late (15-21) shift.

```
LM     93235              SNG   3
(Hgl     V 12:59 - Es        A 13:09)
  ATO
 Hgl      306A  V   12:59 306A,339,HE [175A-R] 140    (0)
 Esk      2     K   13:03
 Es       3     A   13:09 HE,411,3
________________________________________________________

LM     93236              SNG   3
(Es      V 13:21 - Hgl       A 13:34)
  ATO
 Es       3     V   13:21 3,412,EH             140    (0)
 Esk      1     A   13:26
          1     V   13:29
 Hgl      306A  A   13:34 EH,338,306A [213B-R]
```

Figure 7: Hengelo-Enschede timetable

2.3 Research Participants & Roles

During the tests, several key stakeholders were actively involved to ensure the experiment ran smoothly and safely. Within the Remote Operations Centre (ROC), the following roles participated:

- The **instructor/research leader**, who manages overall coordination and guidance of the study in the ROC, as well as training the remote driver.
- the **remote driver**, who operated the train remotely during the tests.

Onboard the train, three individuals have specific responsibilities:

- the **Safety Driver (SD)** manages the safe execution of the test run as a backup and would intervene whenever the situation requires it. The SD is authorized to stop the test run or take over control if safety is compromised.
- The **test ride supervisor** is also a qualified train driver or has received specific training and is responsible for implementing safety measures under the ultimate responsibility of the test driver, including giving briefings before and debriefings after the test run. The test ride supervisor was also authorized to stop the test run if safety was at risk.
- Lastly, the **test leader** is responsible for carrying out the test plan and discusses it during the briefing, they do not have specific authority regarding the safe execution of the test run. The test leader on the train is in charge of the overall study amongst the different test locations.

During the tests, **technical support** is offered remotely by system experts of CAF. During some test days the technical experts are also present onboard of the train. A digital video connection (Microsoft Teams) is used to connect all participants at the various locations and communicate during the experiments.

The test- and research leaders are actively involved in the project; this small group of operational experts and researchers were trained by experts that have operated in similar roles during earlier remote driving studies of NS. The SD and test ride supervisor are supplied by TreinTestCentrum (TTC) and have special qualifications for performing test work. They have different levels of experience with remote driving and Automatic Train Operation (ATO). Some TTC drivers involved in this experiment have previously been involved in remote driving tests in the role of safety driver.

Due to the complexity of becoming accustomed to both the ATO-GoA2 and RTO systems, it was decided to only invite drivers for the role of RD that have previous experience with both systems. All the drivers in the RTO-GoA2 study were therefore supplied from TTC:

- **TreinTestCentrum (TTC):** Drivers from NS's department for test activities with trains. These drivers are used to operating in unusual scenario's and handling new systems.

The train drivers of TTC have been assigned by the planning department without specific selection criteria. All train drivers involved in the experiment were qualified train drivers, holding specific qualifications for the used train asset as well as the necessary certificates for operating in the test environment.

All the involved drivers have previously completed their RTO-training (as described in D38.1) and participated in a RTO-GoA1 test day, prior to their participation with the RTO-GoA2 system.

3 TECHNICAL SOLUTION

This section describes the technical solution that was implemented for the RTO-GoA2 tests. The base of this solution consists of the combination of different systems:

(1) The RTO base solution, both onboard and in the ROC.

(2) The ATO-GoA2 over lineside signalling solution.

The RTO solution has been implemented and demonstrated as part of the remote driving tests that are described in the D38.2 deliverable. This solution has remained largely unchanged for the RTO-GoA2 tests, except for the addition of the specific command- and user interfaces for supporting remote operation of ATO-GoA2 functionalities.

The ATO-GoA2 solution over ETCS or ATB was developed prior to this project by NS and CAF, and has previously undergone extensive testing in the Netherlands. It also forms the basis for the ATO-GoA4 tests as described in D38.4 [2].

The focus of the technical solution as described in this document is focused on supporting the interoperability between these two systems, including the required development of actuators and user interfaces to the RTO-solution to support ATO-operations. This document first describes the applied ATO-GoA2 solution, and then describes the changes to the RTO base solution that are required to remotely operate the ATO-GoA2 functionality. It will only describe the new features that are implemented, and will not again describe the base solution of RTO to reduce duplicate contents. This input can instead be found in D38.2 (RTO base solution) and D38.4 (ATO-GoA4).

3.1 ATO-GoA2 Solution

ATO covers a wide range of applications from manually assisted to fully automated train operation. The possible operation depends on the desired Grade Of Automation (GoA) and the automation level supported by IM on a specific route. At GoA2 level (semiautomated train operation) the train driver is in the cabin. The train is driven automatically, stopping is automated but a driver in the cab is required to start automatic driving of the train, the driver can operate the doors (although this can also be done automatically), the driver is still in the cab to check the track ahead is clear and carry out other manual functions. The driver can take over in emergency or degraded situations.

3.1.1 ATB specific functions

The signalling available on route is mixed, presenting centralised signalling commanded by route controller and non-centralised signalling triggered by local ATB interlocking mechanisms. ATO can know the actual status of centralised signalling from data received from ATO-TS, however, non-centralised signalling status is not available for the trackside system and therefore cannot be reported to ATO. It was therefore required to introduce a PER-system to detect the status of non-centralised signals using image processing, providing the actual signal aspect for ATO's driving strategy. The signal recognition is not based on a high integrity-based system; therefore, it requires supervision by a driver (in the case of this study the RD). A signal proposal handling mechanism is introduced for that purpose by adding a Driver Machine Interaction (DMI) and a numpad to the ROC's steering desk. Whenever a signal is detected by PER and matched with the theoretical location on digital map by SCV, an integrity score is assigned to that detection based on detection probability and status estimation from overall fleet plan. If the integrity score is low, a proposal is sent to the driver and shown on ATO-DMI. The RD can then confirm the proposal or change signal aspect to the correct one. The final signal aspect is then processed by the SCV system, generating a new speed restriction profile that is taken by ATO to generate driving profiles.

In contrast to the ETCS Level 2 implementation of ATO where positioning information is provided by ETCS-balises, no such balises are available in the Dutch ATB system. The ATO-system therefore requires another source for positioning information. This has been established using a proprietary positioning solution based on GNSS and virtual balise positioning, to position the train in ETCS references so that the onboard ATO can operate under all the necessary operational conditions.

It is important to note that due to derogation restrictions, it was not possible to change the ETCS-On board (OB) to be compatible with ATO-OB as TSI2023 [3] determines. For this reason, we have put in an adapter that also includes an extra DMI for ATO (according TSI2023 ATO info should be included in ETCS DMI). On the other hand, we also do not have a standard ATO-TS in this solution but NS have put an adapter in between. Despite all this, the Automatic Driving Module (ADM) ATO-OB module of the project is fully compatible with the ATO-OB module defined in the TSI2023 (this module speaks Subset-130 [4] with ETCS-OB adaptor, Subset-126 [5] with ATO-TS adaptor and Subset-139 [6] with Train Control and Management System (TCMS)).

The ATO tested in the trials is the latest CAF version which is compliant with the TSI released in 2023. These tests have served to check its correct operation.

3.1.2 Required Adaptors

Since the train used for testing has an ATP without interface to the ATO and the trackside system does not implement the standard interface to the ATO-OB the following adapters are required:

3.1.2.1 TP (ATP) Adaptor

As the current ETCS installed on the train does not natively support Subset-130 [4] interface with ATO, TP (ATP) Adaptor was introduced to gather all the needed information via data logging and maintenance services of the ETCS, process it, and send it to ATO in static and dynamic information packets. This information includes operational conditions, odometry, positioning, balise information, speed profiles, movement authorities etc. It also gathers data from TCMS to be able to show traction/brake effort in ATO DMI.

3.1.2.2 ATO Trackside Adaptor (REP)

The ATO Trackside Adaptor (known as REP in X2RAIL4 logical architecture), developed by NS (Newton team), is responsible for giving the ATO On Board and TP (ATP) Adaptor the infrastructure (Segment Profile) and timetable-related (Journey Profile) data to be able to drive the track. This includes the position of stopping points, as well as the arrival and departure time for each stopping point.

REP also implements the servers for ATO-DMI functionality to show the driver information about ATO operation such as ATO state and remaining distance.

3.1.3 Localisation System based on GPS (LZ)

Over STM-ATB, a GNSS based Localization System (LZ) was developed to feed ATO with ETCS-like positioning. LZ is formed by 2 subsystems: GNSS based positioning and Virtual balise reference convertor.

The first one, is responsible for giving accurate latitude and longitude positioning within the track by using a GPS receiver, inertial sensors and information on track infrastructure.

The second one compares the latitude and longitude coordinates sent by GNSS subsystem with the ones of the virtual balises that are received in the Digital Map (DM). This comparison is made through the haversine formula, which determines the great-circle distance between two points on a sphere given their latitudes and longitudes.

3.1.3.1 Accurate stops

The GNSS based localization system was meant to provide ATO with very accurate positioning when the train crossed a new virtual balise. After that, LZ would rely on odometry for positioning, what would increase its positioning error gradually as the train would move away from the reference balise. When approaching a stopping point, this positioning error could be notoriously high, making a human driver outperform ATO in stopping accuracy. To fix this issue, it was decided to develop a relocation mechanism based on landmark detection by PER to mitigate the positioning error just before stopping the train.

This mechanism relies on the fact that LZ system knows the absolute positioning of different landmarks thanks to the DM. Given that LZ also knows the absolute position of the train and that PER can detect and measure the relative distance from the train to some of these landmarks, LZ utilizes these measurements as input to extrapolate the absolute positioning of the landmarks according to PER. After that, LZ corrects the train positioning to make the absolute position of the landmarks estimated by PER match the absolute position of the landmarks in the DM.

3.1.4 Lateral Signalling Identification (PER+SCV)

ATO expects to receive dynamic information such as speed limits and authority of movement from ETCS in Subset-130 [4]. Over ATB lines, a new solution is proposed where this information is sent by ATP Adaptor after receiving it from SCV, who combines static information about the operation (static speed limits, signal locations) with dynamic light signal aspects provided by PER.

3.1.4.1 Signal Detection - PER

PER is responsible for visually detecting light signals and determining their aspects, before sending them to SCV. Note that PER has little knowledge about the train operation and track topology (i.e. location of signals and signs); instead, it detects objects independently in sensor inputs, and it is SCV who filters the proposals and who tries to match them with the signals in DM.

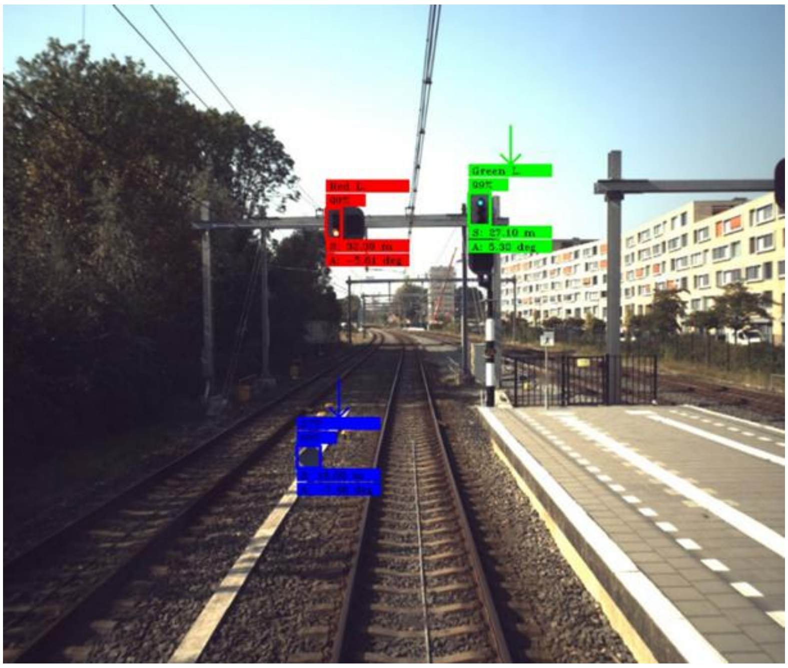

Figure 8: PER output example scene with Green proposed as aspect for next light signal and STP identified as landmark.

Figure 9: PER output example scene at night, with consecutive frames where the green light is blinking being off (left) and on (right). PER proposes its aspect as Flashing Green 6.

PER uses a stereo-vision camera as input to visually detect signals. As seen in Figure 8, the input consists of a Red Green Blue (RGB) image with a synchronized disparity map computed inside the sensor, matching the pixels between the two previously calibrated cameras that integrate it. Sensor management module configures the sensor, reads its inputs, processes them, and records them in video.

After receiving the input, these are the main high-level steps that PER performs for the signal detection functionality:

- Object Detection. A Convolutional Neural Network (CNN) is used as AI model for Object Detection, with classes for Light Signals, Dynamic ATB Panels and static signs such as speed increase announcements, stopping points etc.

- Bounding Box Tracking. A tracker based on Kalman Filters is applied to the detections, to filter False Positives and False Negatives and to assign unique ID-s to the detections.
- Number classification. A separate CNN is used to classify the number inside the objects that may contain them (dynamic and static speed limits, stopping points).
- 3D positioning. Regions defined by the Bounding Boxes are analysed in the disparity map provided by the sensor. Using known intrinsic and extrinsic calibrations, tri-dimensional position relative to the train front can be estimated.
- Track positioning. 3D position is translated into distance over the predicted path of the train, and the distance from the object to the middle of the tracks. This step could have different inputs in the generic solution (a 2D Digital Map, visual segmentation of tracks…), but provisionally, a simple assumption is made: tracks tend to straighten in short distances.
- Custom filters. Various filters were implemented to work over the detected & positioned objects; most notably:
  - Correlation. Light signals and adjacent ATB Panels are matched together, to include the number inside the panel in the final aspect proposal.
  - Flashing. Flashing or blinking events are detected leveraging the unique ID assigned by trackers to individual signals. ON/OFF sequences for a single signal can be tracked across time.
  - Applicability. For scenarios where multiple signals are visible (signals for other adjacent tracks, for example), custom applicability filters were developed taking into account the estimated distance to the train's track.
  - Interface with SCV. Internal structures of PER are translated into signal aspect proposals expected by SCV.

3.1.4.2 Lateral signal converter - SCV

As its name suggests, the Signal ConVerter (SCV) is the system in charge of converting the lateral signalling to the speed limits that ATO needs to drive the train. To do that, the first step is to identify all the side signs and light signals found across the track, as a human driver would do. Over ATB, the lateral signalling is formed by both side signs and light signals.

- Matching PER detection - Digital Map

Side signs are static signalling whose position and speed restrictions are sent through the DM, so SCV's work when identifying them is trivial. SCV just iterates the DM, reading the ID, position, offset and speed limit of each of the signs and saves this information in a vector for future use.

Regarding the light signals, their position is sent through the DM, but since the information they provide is dynamic, SCV depends on PER to identify their aspect as a human driver would do. It is worth mentioning here that while SCV reads the absolute position of all the signals from the DM, PER sends the relative position of these signals considering the active cabin as reference. Therefore, SCV extrapolates the absolute position of the signals detected by PER and filters out all the ones that do not lay where they are expected according to the DM. If the train encounters a grid of signals, this position filter would not be enough to match the DM signal with the physical signal next to the track, so SCV also relies on PER to know which of all the signals that PER is detecting is the applicable one.

- Signal aspect confirmation

To guarantee that ATO does not drive under a wrong speed restriction due to a mismatch in the signal detection, SCV proposes all the light signal aspects to the driver through the ATO-DMI and waits for confirmation or correction before updating the speed limits accordingly. Depending on certain conditions, a signal detected by PER and already identified by SCV is sent to the ATO-DMI with low confidence, high confidence or it is not even sent at all.

When SCV receives a new signal aspect from PER, SCV first checks whether it passes the position filter, is applicable and PER's detection confidence on the aspect (the percentage confidence with which the model claims to have classified an element) reaches the specified threshold. This threshold varied depending on the AI model version, but a value of 70% was one of the most used. If these conditions are not met, the aspect is not even going to be sent to the ATO-DMI.

If the previous conditions are met, SCV then checks whether the driver already confirmed or corrected this signal before. If this is the case, the signal is only going to be sent to the ATO-DMI if the signal was red and the train is stopped. This way, SCV is not going to annoy the driver with too many proposals. The special scenario in which the signal was red and the train is stopped in front of it, the proposal is sent with low confidence, because it is likely that the signal aspect changed, and this proposal should not be discarded. In any other situations where the signal was already confirmed or corrected by the driver and its aspect switched, it was decided that it is the driver who should modify the aspect manually again.

Lastly, the ATO-DMI confirms automatically those aspects that are proposed with high confidence by SCV and asks the driver to confirm or correct manually those that are proposed with low confidence. Nevertheless, even if an aspect proposal is automatically accepted by the ATO-DMI, the driver has always the chance to modify it manually.

- MRSP and braking criterium profiles

The last step in converting the lateral signalling to the speed limits that ATO needs to drive is to calculate the so-called Most Restrictive Speed Profile (MRSP) and braking criterium profile. The MRSP is a vector containing the actual speed limits that ATO shall comply with and the braking criterium profile is a vector containing the locations at which the train shall start braking to reach the speed limits in time. To do that, SCV handles the side signs and the light signals independently and builds a MRSP and a braking criterium profile for each of them.

As mentioned before, converting the side signs to speed limits is a trivial task for SCV, since these speed limits are already read in the DM and can directly be utilized to build the sign MRSP. Furthermore, the DM also sends an offset as attribute for each of the side signs and this is indeed the information needed to build the sign braking criterium profile. Once the sign MRSP and sign braking criterium profile are calculated, SCV does not modify them unless a new DM arrives.

When it comes to light signals, constructing the MRSP and braking criterium profile is a notoriously more challenging task. Not only because the signal aspects need to be interpreted to speed limits, but also because this information is dynamic and, therefore, the speed profiles need to be constantly updated.

One more thing that SCV handles is the so-called ping-in-de-rug. Ping-in-de-rugs are notifications that the driver receives when there is an increase in the ATB speed limit, to make them aware that the allowed speed is greater now. SCV has access to the ATB speed limit and is constantly checking it and comparing it with the allowed speed limit according to the lateral signalling. If this speed happens to be greater, SCV sends a ping-in-de-rug request to the ATO-DMI and, after it receives confirmation from the ATO-DMI, the MRSP is updated consequently.

- Updated TP (ATP) Adaptor

This adapter had to be extended so that it could process positioning information, movement authority and speed limits received from SCV and LZ modules and translate them into a language understandable by ATO through the standard Subset-130 [4] interface.

- Updated ATO Trackside Adaptor (REP)

ATO Trackside Adaptor module was also extended from the one used to drive over ETCS, sending additional information to TP (ATP) Adaptor, LZ and SCV such as DM with all physical locations of infrastructure and virtual balises. Apart from that, this version of the ATO-DMI functionality also handles SCV aspect proposal confirmation and overrides by the driver.

3.1.5 ATO Trackside

The ATO-trackside (ATO-TS) has the function of providing journey profile, segment profile and mission profile data to the ATO on-board (ATO-OB) for the specific GoA2 and GoA4 test scenarios. At this moment in time, there is no ATO-TS nor Traffic Management System (TMS) offered by the infrastructure manager for the applicable test environment, therefore, the trackside system applied during these tests has been constructed by NS, applying existing data processing components from the driver advisory system. The system is based on live data, sometimes with manual adjustments by NS to improve the quality of the data. It is also capable of updating journey or mission profiles to incorporate live updates to the timetable. Figure 10 shows a schematic overview of the NS ATO-TS.

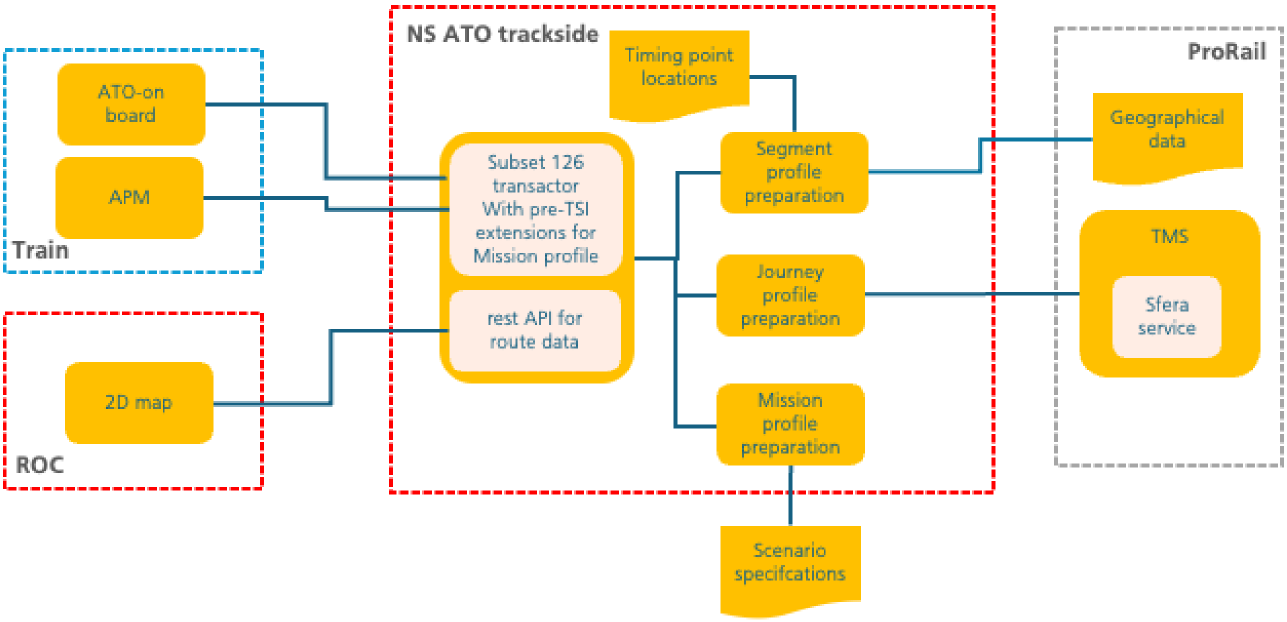

Figure 10: NS ATO-TS schematic overview

The segment profiles are generated from ProRail providing geographical data in proprietary format, this information is then verified against TSI [3] integrity and quality requirements. If necessary, it will be corrected/enriched, this is partly manual procedure. ProRail does provide a SFERA interface to their TMS to provide real time trip data in journey profile structure with links to the appropriate segments for the physical route.

The geographical data and SFERA trip data is combined in the Subset-126 [5] transactor to transmit TSI [3] compliant messages to the ATO OB. The mission profile functionalities are out-of-scope for ATO-GoA2, but have been applied in the ATO-GoA4 tests of D38.4 [2].

The same components are used to provide geographical route data to the 2D map in the ROC.

3.2 Remote Operation Centre

The ROC consists of frontend and backend systems that enable Remote Operations. The frontend consists of a modified Sprinter New Generation (SNG) driver desk, which the RD interacts with to control and monitor the test train from a distance. This includes sending commands to the train and receiving data and video from the train, which is managed by the ROC backend application and displayed by the ROC frontend application. A dedicated VPN provides a secure connection between the train and the ROC and firewalls on the train and in the ROC further protect the connection.

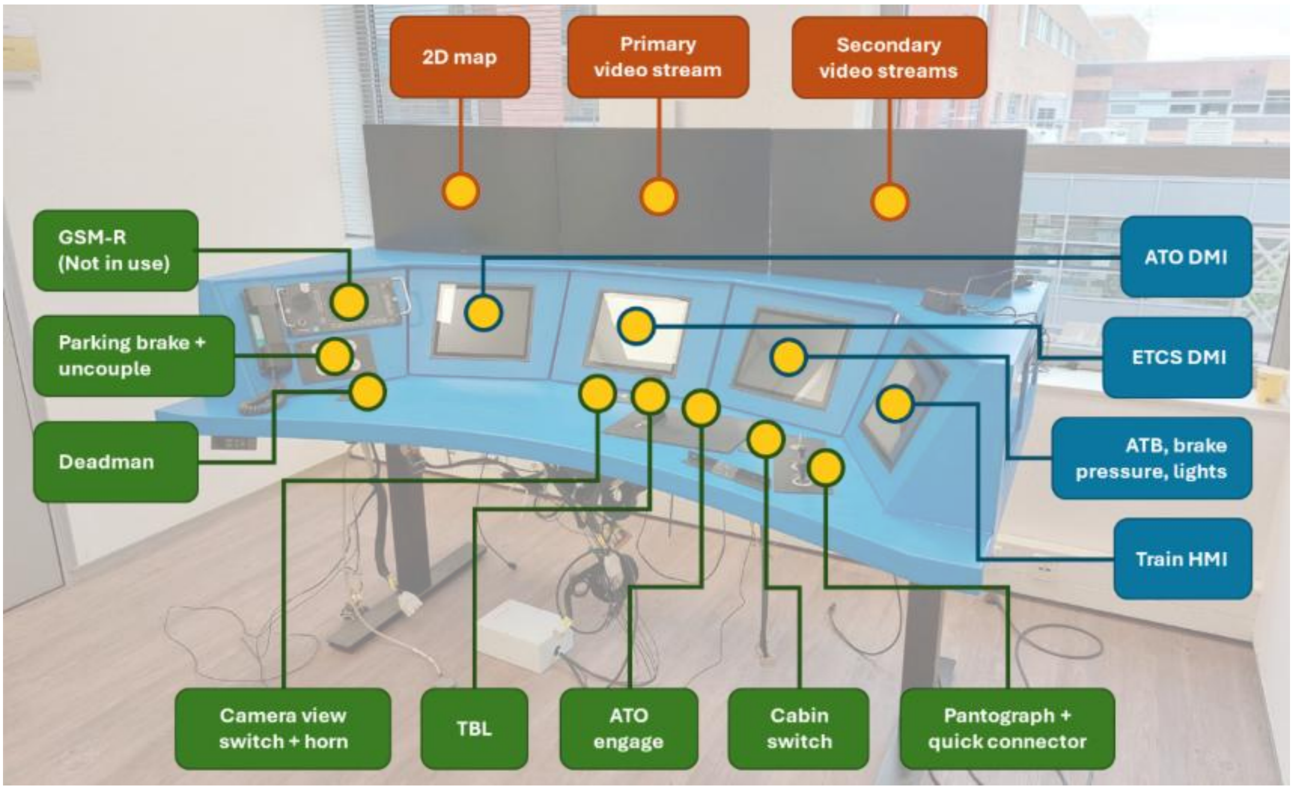

Figure 11: Steering desk functionalities

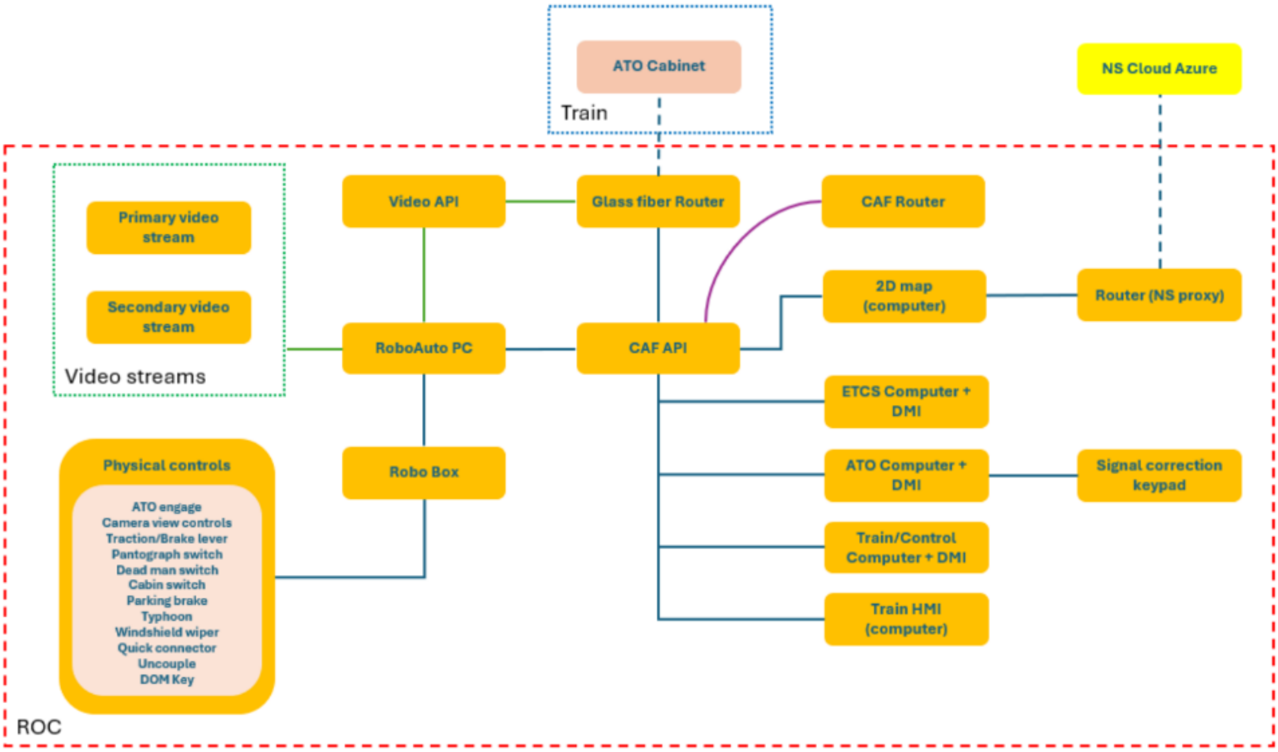

Figure 12: Graphic representation of ROC components

3.2.1 2D Map

The 2D map shows the real-time location of the vehicle selected in the ROC with surrounding tracks and objects. There is no interaction with the remote driver, it only provides additional information to the driver, for situational awareness.

3.2.2 Primary video stream

The primary video stream shows the selected view from one of the cameras. The front perspective (normal zoom and enhanced zoom) can be switched to other views by using the video controls. The speed of the train limits the view of the pantograph and coupling camera, which are deactivated above 15km/h. The remote driver can influence what he sees, pending on the desired primary focus. The purpose is to highlight the focus to the remote operator.

3.2.3 Secondary video stream

The secondary video stream shows the three video streams other than the one selected on the main video stream. All video streams currently show the outside view of the train, front perspective (normal zoom and enhanced zoom) as well as a pantograph and coupling focus camera. Note pantograph and couple camera will be shut down above a speed of 15 km/h.

3.2.4 ETCS DMI

The ETCS DMI shows information to the remote operator, identical to what is presented to the driver in the train. The information contains the train speed, ETCS level or current ATB code. Furthermore, it provides an indicator for an ATB brake intervention, an indicator that the brake criterium is satisfied and an indicator showing that ATB is not in service.

3.2.5 ATO DMI

The ATO DMI shows information to the remote operator about the status of the ATO GoA2 system on the local train. With ATO over ETCS this information is normally integrated within the ETCS DMI, but since the tests are performed over lineside signalling, a custom NS solution was created for previous ATO tests and is used in these tests on a separate display. An important feature specific for lineside signalling is the visualisation of the next signal aspect(s) that ATO has proposed and/or has perceived via image recognition.

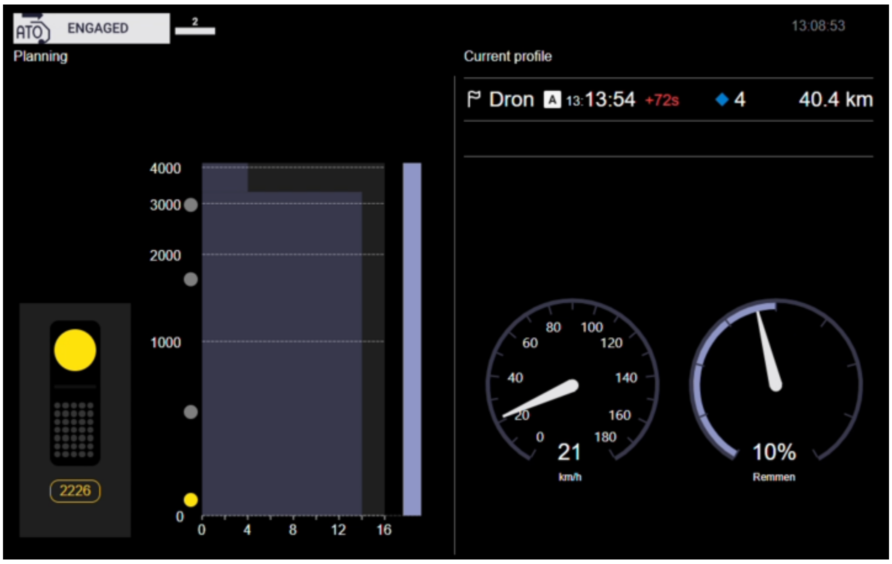

Figure 13: ATO DMI visualisation

3.2.6 Control DMI

The control DMI is the visual interface of the ROC to be able to connect to the train remotely. After startup of the ROC, a login screen and vehicle selection screen is visible. When logged in, the train information is presented which is normally visible on the active cabin by means of physical buttons, lights, gauges. It shows the brake pipe pressure meter, brake cylinder pressure meter, the ABC malfunction indication lights and Deadman light.

3.2.7 Human Machine Interaction

The Human Machine Interaction (HMI) is a representation of the train HMI, where the majority of the functionality is included. Not all regular features are included due to the prototype nature of this solution, i.e. the brake test is not included. It provides the remote operator with different types of information depending on which screen is selected in the train HMI. The screen active when driving, and also the most commonly used screen, is the "driver screen". This screen shows the rolling stock id, service id and train clock (local time) in the header line. Next, it shows the active cabin and train set status. Finally, this screen also shows information regarding the brake/traction demand, battery/catenary voltage, operational mode, driving mode, main pipe pressure and total distance driven. Another commonly used screen is the "station screen" providing information regarding the door/ramp status, also shows the active cabin and provides a list of actual A/B/C category alarms.

3.2.8 Controls

The ROC has the relevant train controls embedded within the desk. The purpose is to recreate the train cabin as good as is possible.

1 ATO engage button
2 Camera view controls
3 Traction / Brake lever
4 Pantograph Switch
5 Dead man switch
6 Cabin selection switch
7 DOM key
8 Signal correction numpad
9 Windshield wiper
10 Quick connector
11 Parking brake
12 Couple / uncouple
13 Horn

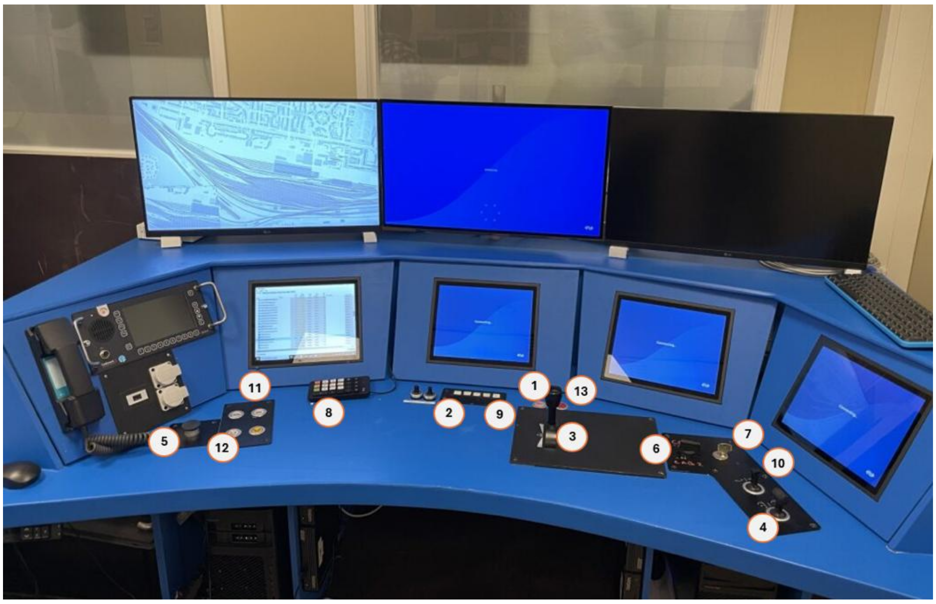

Figure 14: ROC control elements

Specific for lineside signaling a signal correction numpad is available. The RD driver can use this control device to acknowledge or correct a proposition of the expected next signal aspect from the ATO GoA2 system shown in the ATO DMI. The following actions are possible:

Acknowledge a signal aspect via the Enter-button.

Correct the proposed signal aspect by entering the aspect color followed by an optional aspect cypher (i.e. yellow-8) and acknowledge this new signal aspect via the Enter-button.

Cancel a correction via the C-button.

Acknowledge a request from ATO to adhere to a new higher allowed speed via the 'arrow-up' button (in case of signal aspect improvement).

Figure 15: Signal correction numpad

3.3 DIFFERENCE BETWEEN RTO GOA1 & GOA2

The main and only difference of the ROC is that, in addition to all the functionalities already available in the base RTO-solution, the driver can now interact with the onboard ATO GoA2 just as they would from the physical cab.

To enable this interaction, three essential elements have been added:

- Engage Button – Allows activation or disengaging of the ATO mode.
- ATO DMI – Displays and manages ATO-related information.
- Numeric Keypad – Required to confirm or correct signals detected by the lateral signal detection system on the train.

In the RTO-GoA2 mode, the driver is at the ROC with the necessary controls to operate the ATO GoA2 located in the train. In addition to the new interfaces (button & keypad), the remote brake command has also been included, resulting in any brake command of the remote driver acting as a disengagement command for the ATO-system. Allowing the RD to quickly take over control when necessary (i.e. obstacle detected), or they can correct or confirm lateral signal proposals is required.

Commanding ATO to start driving is the responsibility of the RD, and can be done from the ROC. Triggering ATO is done by pressing the ATO engage button on the ROC steering desk, this command is then transmitted to the Remote Driving On Board (RD-OB) unit, which forwards the command to the ATO-system. The RD is also in charge of supervising ATO's performance in accordance with ETCS/ATB movement authorities.

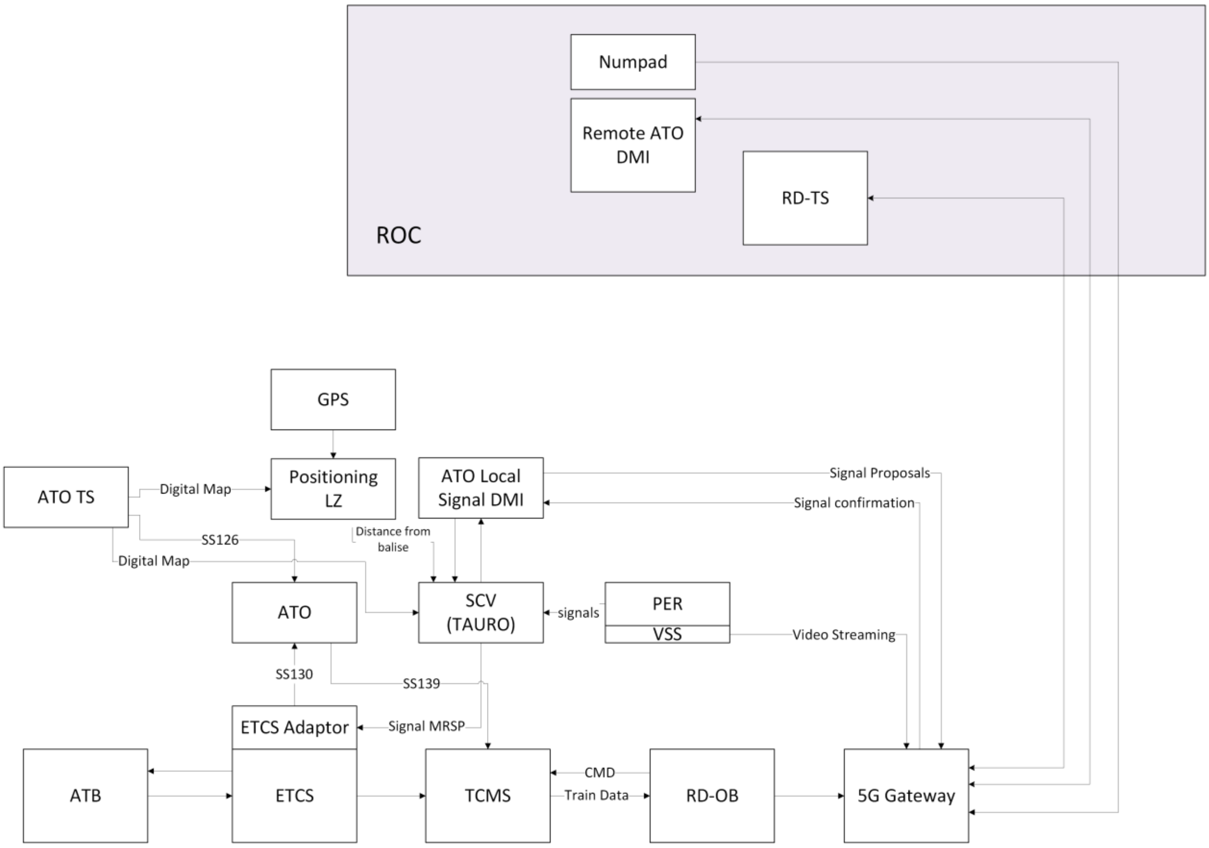

Figure 1616: RTO GoA2 Logical distribution

4 USE-CASES

Monitoring an ATO-GoA2 from the ROC requires some specific interfaces and tasks that are not regularly applied during remote driving, and have thus not been identified in previous work on RTO use-cases. Therefore, new use-cases have been drafted as part of this study to address the specific changes related to the RTO-GoA2 concept. The use-cases were drafted by NS-experts that have previously worked with both ATO and RTO.

A total of 5 new use-cases have been identified:

- **UC-38.3-001 Remote ATO engagement/disengagement:** the remote driver pushes the ATO engagement button available in the ROC. This leads to the engagement/disengagement of the ATO GoA2 system on the local test train.
- **UC-38.3-002 Remote driving with ATO GoA2 monitoring:** the remote driver monitors the actions of the ATO GoA2 system on the local train from the ROC during driving, based on the available visual information from the ATO DMI and the outside view camera images.
- **UC-38.3-003 Remote signal aspect correction:** the remote driver may need to correct the detected signal aspect of the ATO-system. The steps are displayed in Figure 1717.

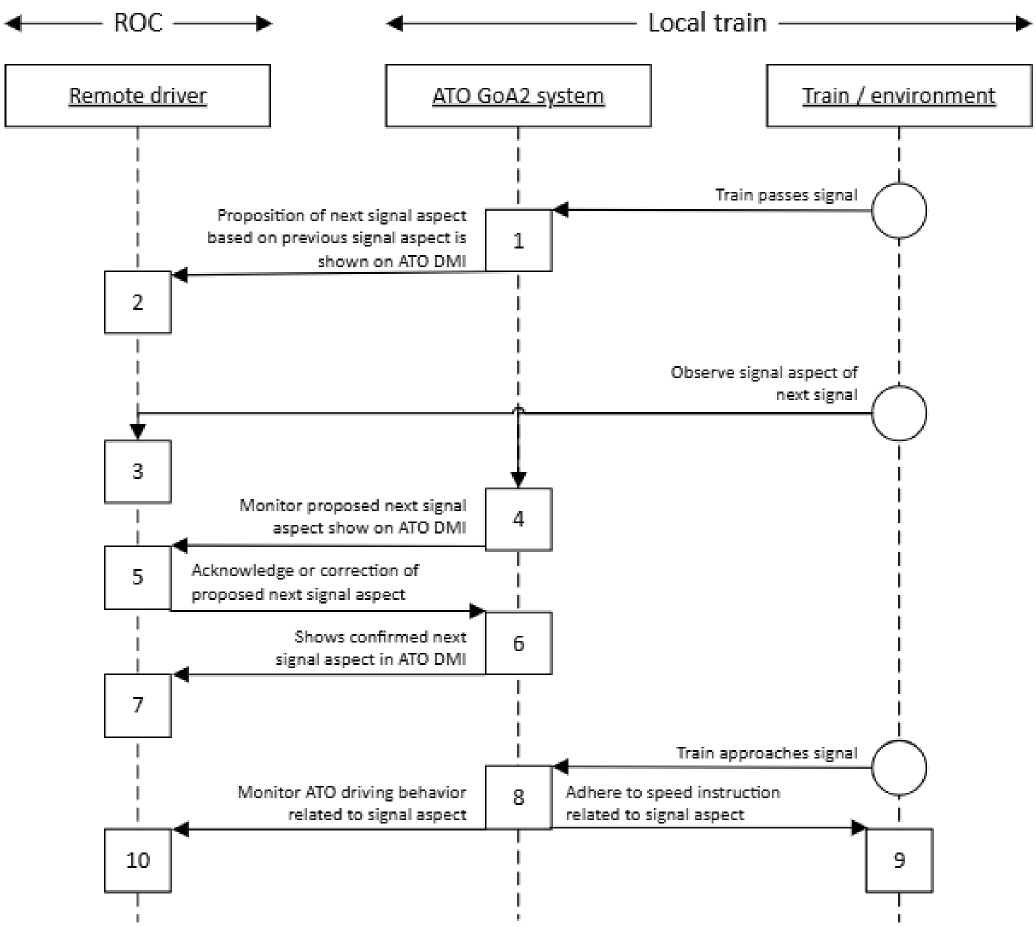

Figure 1717: Swimming lane diagram of use case signal aspect correction

- **UC-38.3-004 Remote halting with ATO GoA2 monitoring:** the ATO GoA2 system automatically halts at the stopping location and disengages itself. The remote driver engages ATO again to depart automatically. Note: opening/closing doors has not been carried out remotely by the remote driver of automatically by the ATO GoA2 system, since this was out of scope of the test solution.
- **UC-38.3-005 Remote intervention:** the remote driver intervenes by braking with the traction-brake-lever available in the ROC and takes over driving control from the ATO GoA2 system on the local train.

Remotely carried out use cases with manual driving are not considered here, since these are part of D38.2. The tasks of (un)coupling has not been included; this functionality is not part of ATO-GoA2 but should be performed either by the remote driver (RTO-GoA1) or automatically (ATO-GoA4).

Driving over non-centrally controlled tracks with or without manual switches has also not been part of the scope in this study due to the lack of infrastructure data, ATP and timetable input.

5 RESULTS

Overall, the tests conducted in the RTO-GoA2 phase went quite smoothly, which can be attributed to a few key factors: 1) The test setup remained largely unchanged compared to RTO-GoA1 and many of the software issues encountered previously were solved, and 2) there were relatively few issues with ATO, as one of the criteria for starting this test phase was that the ATO system is reasonably mature and stable.

Some sporadic issues occurred, such as undershot timing points or misinterpreted signals and signboards, but these were consistently acknowledged by the RDs, who then took appropriate action. In cases where the RD needed to intervene, this was possible with minimal issue, except for the signal aspect corrections which proved to be difficult due to the limited time given for the RD to respond.

As with the RTO-GoA1 tests, there are some limitations of the current setup. It was not designed as a standalone solution, but sometimes required remote support from CAF to reset components or troubleshoot issues that arose during testing. In terms of operational conditions, all tests were conducted during daylight hours under good weather conditions, thus no conclusions can be drawn regarding nighttime or poor visibility operations. And finally, the tests were only conducted with 2 RDs who were already familiar with the ROC setup and the driving behaviour of the ATO system, meaning that their experience is assumed to be less representative of what a RD with less experience with these systems may have. None of these limitations invalidate the research done here, but nonetheless are important to consider when interpreting the results.

5.1 USE-CASE PERFORMANCE

To investigate the technical feasibility of the RTO-GoA2 concept, it was attempted to perform all of the use-cases as described in chapter 4 and observe the task. Each of the use-cases has been applied at least three times.

5.1.1 UC-38.3-001 Remote ATO engagement/disengagement

In general, it was possible for the RD to engage the ATO-GoA2 system from the ROC. When the ATO-system was engaged, it was always possible for the RD to disengage the system; using either (A) the disengagement button or (B) operating the break lever.

There have been occurrences where the remote driver was not able to engage the system; this was not related to the remote connection but rather related to the ATO-system not meeting all the engagement criteria. This is intended behaviour of the system.

5.1.2 UC-38.3-002 Remote driving with GoA2 monitoring.

When the train is operating under RTO-GoA2 and driving under ATO, the driver was successfully able to monitor the outside world and the driving performance of ATO. This has been validated in a driving scenario with big margins and with no time pressure; i.e. stopping at a platform while having a long movement authority or approaching a red signal while driving at a relatively low speed and with a 50m stopping margin.

While the drivers report being confident on performing the remote supervision of ATO within these safe operating conditions – and under the supervision of safety drivers -, they have reported to be hesitant to monitor the ATO-system remotely when operating close to margins. When operating remotely – and thus having additional delays compared to on-board – it may reduce the available time to intervene. Example scenarios include ATO applying operating speeds close to the permitted speed of ETCS, especially in slippery conditions.

5.1.3 UC-38.3-003 Remote signal aspect correction

For most of the signals that were passed, the signal aspect that was detected by ATO was correct and did not require any intervention of the RD. However, in some scenarios (especially under difficult lighting conditions), it was required for the RD to correct the signal. This functionality has proven to be technically possible.

However, the practical applicability of this functionality with the current state of technology has been proven to be limited with the current capabilities of the perception system. The involved ATO-system was able to reliably interpret the signal aspect at an average distance of 30 to 40 meters prior to passing the signal. With an operating speed of 125km/h, and the requirement to perform signal corrections before passing the signal, it leaves approximately 1 second to perform the signal recognition. Sensors capable of seeing farther are necessary to improve the system.

Performing signal corrections involves several steps:

1. System: Sending of interpreted signal from ATO-OB to ROC.
2. RD: Interpreting the proposed signal by the RD.
3. RD: Confirming if the proposed signal is correct.
4. RD: If incorrect; inputting the correct signal conditions in the DMI:
    a. Signal color
    b. Is the color blinking or not?
    c. Signal number
    d. Is the number blinking or not?
    e. Confirming the input.
5. System: Sending of the driver's signal input to the ATO-OB.

In general, it was not possible to perform this sequence of actions within the 1 second of reaction time when operating at 125km/h. Only when the ATO-system detected signals at an earlier moment, or when driving with a lower operating speed did it allow the RD to perform the use-case successfully before passing the signal.

It was possible to perform this use-case in scenarios where the signal was discovered at an earlier moment, or with a lower operating speed, allowing for the RD to have more time to respond. The improvements of the perception sensors and algorithms in future projects could contribute to improve the timely detection of signals, allowing the driver more time to perform the (remote) signal aspect corrections.

5.1.4 UC-38.3-004 Remote halting with ATO GoA2 monitoring

The RD was successfully able to supervise the ATO-GoA2 system while it was approaching towards and halting at the passenger station. The functionality of closing the doors was not implemented and has therefore not been tested.

The RD was successfully able to re-engage ATO to depart at the correct departure time.

5.1.5 UC-38.3-005 Remote intervention

The RD was successfully able to intervene remotely and take over control from the ATO-system. This was tested by performing braking effort from the ROC, resulting in the ATO-system disengaging on-board of the train.

5.2 RD USER EXPERIENCE

One of the goals of this study is to find out whether the remote operators experience a difference in monitoring the ATO system (GoA2) compared to driving the train remotely (GoA1). To answer this question, two remote drivers were asked separately about their experiences with driving remotely under both GoA1 and GoA2. It is important to mention that these RDs have been involved in previous ATO-GoA2 and RTO tests and are very accustomed with the technological solutions.

In conclusion, both remote operators felt minimal difference between remote driving under GoA1 & GoA2. This was mainly due to the fact that both RDs have built up confidence in the ATO system over time, because it has often been seen that, among other things, the braking actions went well and did not cause any problems during monitoring. Furthermore, the braking actions by the ATO system are deployed relatively late, but after the RDs have seen that this doesn't cause a problem, both in RTO and previous ATO-GoA2 testing, sufficient confidence was built up. Finally, the RDs were always able to intervene safely. For example, a RD once intervened at a red signal, as ATO did not initiate braking. Since driving through a red light is seen as a no go, the RD did not want to wait too long before taking action. Despite this event, the RD still had a good sense of safety and felt in control of the train. However, it should also be mentioned that one of the RDs also admitted to get distracted more easily under the RTO-GoA2 concept compared to the RTO-GoA1 concept due to the lack of active tasks. In addition, the RD experiences regarding safety and control are based on 2 RDs who are very familiar with the ROC and ATO systems, so their experiences may not be representative for all potential future Remote Operators. A recommendation from this work is therefore that future work on RTO needs to include other drivers with a range of experience to get a better idea of the impact of RTO on the RD.

Furthermore, the remote connection was also discussed with both RD's. While there were some issues with unstable connections within this test environment (further discussed in D38.2), both RDs mentioned that remotely monitoring the train still felt safe. This is mostly due to the fact that in the event of a control connection loss, the full service brake will be deployed. This would ensure that the system would still operate safely even if there appears a loss of control connection. The issues with the signal aspect correction were mentioned as difficult, but they expect this to be resolved in future technical solutions.

6 CONCLUSION

The conclusions presented in this section focus on the functionality of RTO GoA2 itself, without assessing the local ATO GoA2 on the train, which was not part of this deliverable.

From a technical perspective, the system operated within the established margins. The new actuators and indicators added for interaction with the local ATO GoA2 worked within the latencies already known in the RTO GoA1 system. It should be noted that only a handful of variables were added to the transmission and reception of the list of telecommands and data received from the train—an insignificant load that had no impact on latency or computational load compared to the previous RTO GoA1 solution.

The only functionality affected by latency throughout its entire execution cycle (system + human factors) is the confirmation or correction of lateral signals by the remote driver. Since this cycle involves several steps, actors and factors, and the train operates at speeds of up to 125 km/h, the time available after the system recognizes the applicable signal may not be sufficient for the drivers. The signal is detected on time, but determining whether it is the applicable one requires being closer. Possible solutions include implementing better sensors with greater zoom or reducing the operating speed to 80–100 km/h with the current configuration.

From a user's perspective, remote monitoring of ATO driving was successful under safe conditions with ample margins, although the RD's confidence decreased when operating close to safety limits due to increased reaction times inherent in remote supervision. Remote signal aspect correction proved technically feasible but currently limited in practical applicability at higher speeds, as the short time frame required for signal recognition and correction challenges timely RD interaction. Remote halting and departure supervision worked effectively, though door control was not yet tested. Finally, remote intervention demonstrated the ability for the RD to safely take over and deactivate the ATO system on demand.

In addition, the study found that the experienced remote drivers perceived minimal difference between remotely driving the train under GoA1 and monitoring the ATO system under GoA2. Their confidence in the ATO system's performance, especially in braking actions, contributed to a strong sense of safety and control during remote supervision. Although occasional interventions were necessary, such as at a red signal, the remote drivers consistently felt capable of taking timely and safe action. One remote driver noted slightly higher distraction under the GoA2 concept, highlighting potential areas for attention.

It is important to recognize that these findings are based on the insights of two highly experienced drivers familiar with both the ROC and ATO technology. Therefore, they may not represent the broader population of future remote operators. Future research should involve drivers with varied experience levels to better understand the overall impact of RTO on remote driving performance and safety perception. It should also look into the applicability of the ATO-GoA2 solution for shunting and stabling procedures in the presence of limited ATP-protection areas (i.e. ETCS shunting or onsight, or ATB Non-Centrally controlled areas).

The work performed in this study provides a first glance at the potential application of the RTO-GoA2 concept. Future work is required to investigate the benefits of this combining RTO and ATO-GoA2 compared to RTO as a stand-alone concept, as well as further proving the use-cases in more complex operational scenarios. It should also further investigate the human-factors related topics of remotely monitoring a train.

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