Rail to Digital automated up to autonomous train operation

D38.7 – Results of remotely controlled shunting

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EXECUTIVE SUMMARY

Task 38.7 "Moving a train within a yard by remote control (shunting)" 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 of remote driving that could enable automatic stabling, shunting and non-commercial runs. This task aims to assess the impact of Remote Train Operation on the efficiency of shunting processes.

In the period between 5 February and 31 March 2024, the SBB test operation of shunting movements controlled remotely from a remote control centre took place in Zurich (Switzerland). 24 test candidates, acting as remote operators, in Zurich-Oerlikon controlled an Aem 940 locomotive, which was located 8km away in Zurich-Mülligen. The test candidates were engine drivers of SBB Passenger services, SBB Freight services and SBB Infrastructure of different age and categories.

The central component of the SBB demonstrator was to test movements in shunting yards by remote control with focus on HTO requirements (human-technology-organisation). The HTO analyses on remote shunting operations was carried out by the German Aerospace Centre (DLR) and can be found as a standalone report (see chapter 7 - Reference). The remote control-system was provided by Alstom.

The results showed that remote control is applicable with regards to HTO.

For increased handling safety and efficiency, tactile (e.g. shaking of the master controller in the event of wheel slip / wheel slide) and acoustic feedback is recommended. The information about the precise position (localisation), the signals to be observed (e.g. signals behind or in the blind spot of the vehicle) and the direction of view (direction of view/direction of travel) are essential for the remote operator to start a safe manoeuvre.

The average value of the latency was in the range of 500ms with minimum values around 300ms and maximum values around 750ms (4G/5G public network). Under these conditions, shunting tasks at speed of up to 30km/h are manageable. The precondition is that the latency is not exposed to major fluctuations so that the remote operator is not surprised by a sudden, significantly delayed response from the remote-controlled vehicle at a crucial moment.

High image quality (resolution and true colour reproduction) in all lighting and visibility conditions is essential for safe operation. The test runs have shown that the recognisability of signals, position of the switch and obstacles (e.g. drag shoes) at speed up to 30km/h should be ensured over a minimum distance of 100m.

In remote control mode, precise and reliable communication between all process participants is crucial as nobody is on site on the vehicle.

Regarding ergonomics, it was determined that the changed driving feel must be compensated by specific indicated information. For example, in remote-controlled shunting mode, the speed should be displayed in the remote operator's central field of vision with a scale of tenths of a kilometre (0.1km/h). Such a speed indicator can partially compensate the lack of driving feel.

ABBREVIATIONS AND ACRONYMS

ATO	Automatic Train Operation
BZ	Betriebszentrale (Traffic Control Centre)
DLR	Deutsches Zentrum für Luft- und Raumfahrt
	(German Aerospace Center - Institute of Transportation Systems, Dpt. Rail Transport Systems and Technologies)
DMI	Driver Machine Interface
ETCS	European Train Control System
FDV	Fahrdienstvorschriften (Operation Regulations)
GoA	Grade of Automation
GPS	Global Positioning System
HTO	Human Technology Organisation
ILTIS	Integral control and information system (Switzerland)
SBB	Schweizerische Bundesbahn (Swiss Federal Railways)
R2DATO	Rail to Digital automated up to autonomous train operation

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1 INTRODUCTION

Task 38.7 “Moving a train within a yard by remote control (shunting)” 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 that could enable automatic stabling, shunting and non-commercial runs.

The demonstrators within WP38 have been designed to show the performance of ATO and remote driving technologies in an operational environment, integrated in an existing trainset that operates on public tracks.

This deliverable “D38.7 – Results of remotely controlled shunting” is the outcome of Task 38.7 and describes the moving of a train within a yard by remote control that was tested for the WP38 demonstrators. The exact description of this task is mentioned in the Grant Agreement:

> *“Moving a train within a yard by remote control (shunting)*
>
> *This work package tests moving of a train within a yard (e.g., from a stabling track to a service track and vice versa) by remote control. This includes tests on shunting yards in Switzerland by SBB.”*

The SBB demonstrator investigates movements of a locomotive within a shunting yard and the use case as a fallback level, for GoA 3/4. The focus relies on the HTO (humans, technology and organisation) analysis. The findings are summarized in implementation recommendations. These implementation recommendations could support future projects concerning remote controlled shunting and train movements when defining requirements. In addition to this deliverable, the detailed study regarding the HTO analyses by DLR is available on its public library (see chapter 7 - Reference).

1.1 Scope

The demonstrator primarily focused on utilizing an existing system to gain insights into human factors. It was a stand-alone system independent of ATO (GoA2, GoA3/4). The system was installed for approximately 3 months for testing purposes. After that, it was dismantled. For the test only one side of the vehicle was equipped with such a remote control system.

1.2 Project Relations

The study that is described in this document is a stand-alone research project by SBB and does not directly relate to the study of NS that is described in D38.1, D38.2, D38.3, D38.4 and D38.6. There is also no relation to the NG Brake study of Knorr-Bremse as described in D38.5.

The results of this study can therefore be read as an independent study. However, there are many connections to the externally published study by DLR (see chapter 7 - Reference) which was conducted on a contract basis for SBB.

2 PROJECT DESCRIPTION AND IMPLEMENTATION

This section describes the project partners and the applied safety concept.

2.1 PROJECT PARTNERS

The work of the parties listed below has been carried out on a contractual basis with SBB. It was independent of their participation in the ERJU.

2.1.1 DLR

The German Aerospace Centre (DLR - Deutsche Zentrum für Luft- und Raumfahrt) is the research centre of the Federal Republic of Germany for aeronautics and space, as well as for energy, transport, digitalisation and safety in the field of applied sciences and basic research. Within the DLR, SBB contracted the Institute of Transportation Systems to conduct the HTO analysis.

2.1.2 Alstom

Alstom S.A. is a manufacturer of railway vehicles and systems. Alstom successfully tendered for the SBB demonstrator and was accountable and responsible for the technical part of the remote control (vehicle, communication link, remote control desk).

2.2 SAFETY CONCEPT

A safety concept was generated to ensure the safety of the test run, the personnel involved and overall railway operations. This concept describes the identified risks and its mitigation measures. The safety concept is only applicable to these test runs and was distributed in advance to all parties involved. This details of the safety concept are not part of this deliverable, as it contains confidential information from SBB.

3 TEST SETUP

The tests were carried out in Zurich (Switzerland). The remote control desk was located in Zurich-Oerlikon, around 5.3 km away from the Zurich-Mülligen shunting yard, where the locomotive was located. The traffic control centre (BZ Ost) is located at Zurich Airport approximately 6 km from Zurich Oerlikon. Figure 1, visualizes the different locations in Switzerland (Source: Google Maps).

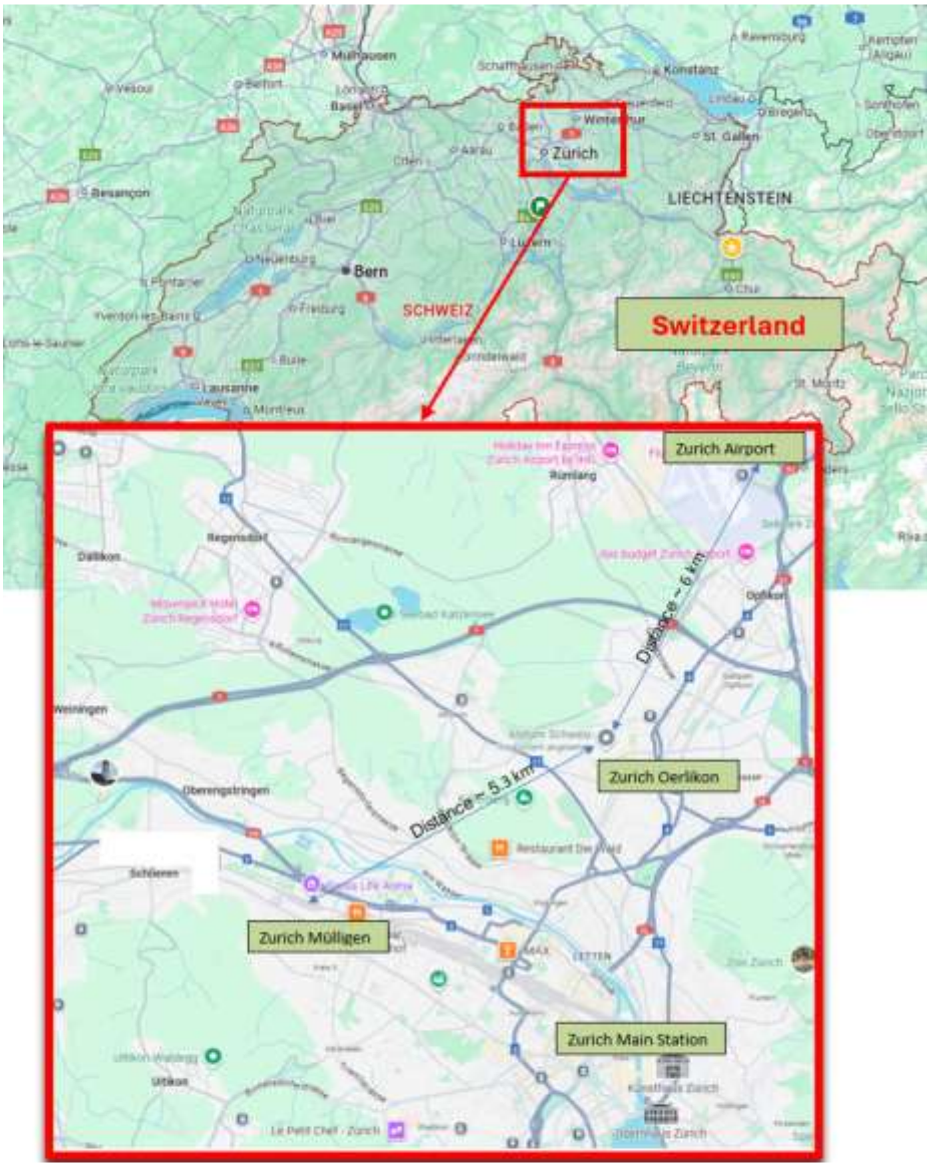


Figure 1: Location of SBB demonstrator

Figure 2, shows the overview of the test environment and data flow. There is a public 4G/5G network in Zurich-Mülligen, which was used for the tests. The moving authority is given by light signals (dwarf signals) located on the left-hand side of the track. Further details of the test are described in the following chapters.

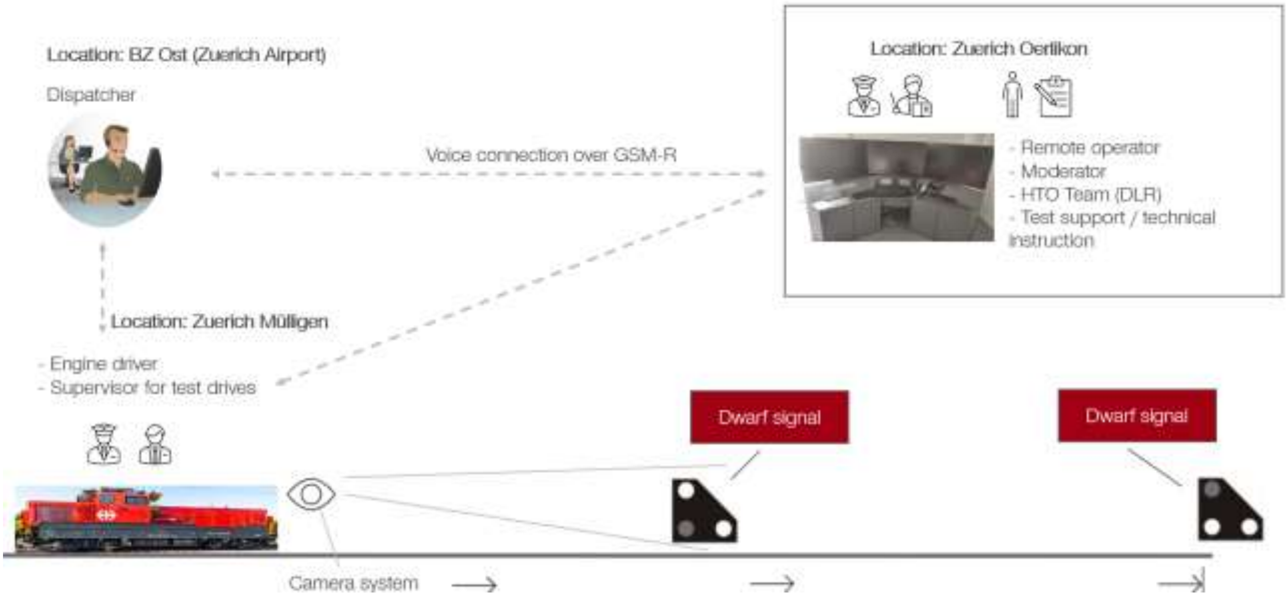


Figure 2 - Concept overview, test environment and data flow

3.1 Locomotive

An Alstom Prima H4 was used as remote-controlled locomotive. Its designation is "Aem 940 029". The remote-controlled locomotive (without trailing load) was located in the shunting yard at Zurich-Mülligen. When the remote control was active, a warning light flashed on the outside of the vehicle.

Figure 3 - Locomotive during a remote-controlled manoeuvre

The transmitted data included video and audio data, control and signal data as well as status information of the locomotive. This data was transmitted over the public 4G/5G network.

3.2 Panoramic view camera

Cameras that allowed a panoramic view were installed inside the driver's cabine in front of the windscreen. The images were visualised on the remote control desk by three large monitors in front of the remote operator. One camera was used per screen on the remote control desk, which can be seen in Figure 6.

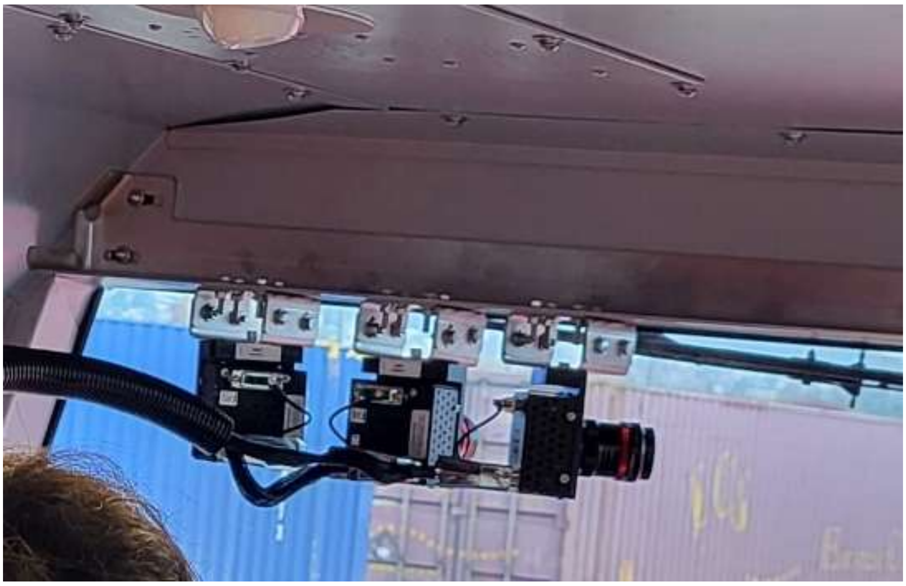


Figure 4 - Installation and arrangement of the cameras in the driver's cab

3.3 Front camera / near field camera

The front camera / near field camera covered the entire area in front of the vehicle (Berne Space - Berner Raum[1)]). It was also possible to recognise dwarf signals next to the track. The dedicated front camera / near field camera was centrally installed on the front side of the locomotive for the close-up area and for visualising the Berne Space on the screen. The image was visualised on the lower central display of the remote control desk (see Figure 7).

[1)] *Remark: In the case of railway vehicles (locomotives, railway carriages), the Berne Space refers to a defined area between two touching vehicles. A secured area is required here in which the railway staff can couple or uncouple the vehicles.*

Figure 5 - Installation and arrangement of the front camera / near field camera

3.4 REMOTE CONTROL DESK

The location of the remote control desk was set up at the headquarter of Alstom Switzerland in Zurich-Oerlikon. The vehicle could be remotely controlled from this location. All journeys with the candidates originated from this location. Instructions, briefings, and debriefings with the candidates were also conducted there.

The remote control desk was used to control the vehicle remotely. In addition to the three large upper panoramic monitors (see Figure 6), three additional smaller displays were available (see Figure 7).

The display on the left-hand side provided information on the integrity status (latency status) and included a Google Maps view for localization. The camera view of the Berne Space was shown on the central display. The right-hand display presented information on speed, pneumatic pressures, line voltage, tractive and braking force, current pantograph position, main circuit breaker and diesel engine status. In addition, the remote operator had electronic access on a separate notebook as well as a hard copy, to the track diagram (interlocking overview plan) to assist with orientation. All camera perspectives were static, the remote operator had no possibility to switch them on the screens.

Figure 6 - Remote control desk with panoramic view during the manoeuvre

Figure 7 - Displays with driving information and video image

A further control panel was located on the left-hand side of the remote control desk as a 15-inch touchscreen:

Figure 8 - Layout of control panel (left) and integration of control panel in driver's desk (right)

The following table lists the available operating elements of the control panel:

Description of operating element
1. Start and stop diesel powerpack
2. Raise and lower current pantograph
3. Main circuit breaker (open / close)
4. Direction: forwards, neutral, reverse
5. Apply and release parking brake
6. Actuate horn
7. Actuate sander
8. Cruise control function / setting the maximum speed of the speed limiter
9. Activation and deactivation of the speed limiter

Table 1 - Operating elements on the remote control touchscreen

Additional support of ILTIS overview

To gain insights into the determination of position, half of the test candidates were provided with an overview image of SBB's ILTIS system (see Figure 9). The ILTIS displays the track diagram of the shunting yard, along with real-time track occupancy (red) and set routes (green). This enabled a comparison with and without ILTIS support. The findings can be found in detail in in the DLR study (see chapter 7 - Reference).

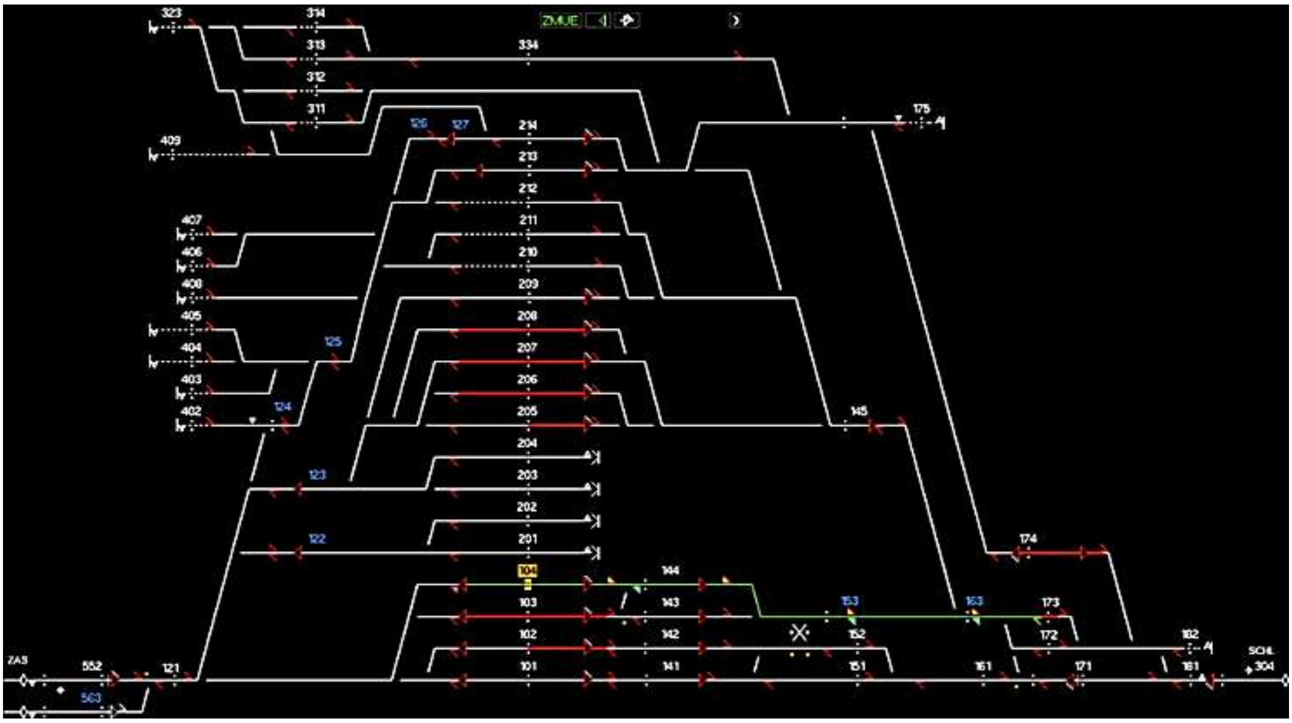


Figure 9 - ILTIS visualisation of track diagram for Zurich-Mülligen shunting yard

4 TEST SCRIPT

A test script was created based on scenarios from shunting operations (see chapter 4.4 - Description of the test scenarios). The test script includes detailed instructions for the personnel involved, outlining the procedures for each test block, briefings and all relevant telephone numbers. Therefore the detailed test script won’t be published.

4.1 SELECTION OF TEST CANDIDATES

In order to ensure a heterogeneous representation of train drivers, the tests were carried out with 24 test candidates acting as remote operators from various SBB business units, each with different levels of professional experience. The different type of test candidates are indicated in Table 2.

Test candidates
Regular locomotive crew from SBB Passenger Services Markets
Regular locomotive crew from SBB
Regular locomotive crew from SBB Infrastructure

Table 2 - Test candidates

The test candidates were between 20 and 59 years old and had between one and 33 years professional experience. Most of the test candidates stated that they know the Zurich-Mülligen shunting yard

The remote operators were permitted to drive in the shunting yard without prior track familiarity. The test staff on the locomotive were kept informed at all times about the candidates' level of knowledge regarding the vehicle and the shunting yard. This allowed them to act appropriately in all situation and to stop movement in case of an emergency.

4.2 Roles

The following roles were defined and involved in the tests (see also Figure 2):

Remote operator, test candidates
Regular engine drivers and shunting locomotive drivers (cat. A, B100, B) took over the role as a remote operator.
Engine drivers for test runs
During the tests, an engine driver was at the driver's desk of the locomotive. They prepared the locomotive, drove to the starting point of the test case, handed over the remote control to the remote operator and monitored the brake test and the movements by the remote operator.
Supervisor for test drive
A supervisor for test drive was in the driver's cab during the test runs (next to the "engine driver for test runs"). He requested the routes from the traffic controller and monitored the test runs. In case of an incident, he could stop the manoeuvre using the emergency button.
Alstom technician
An Alstom employee was responsible for troubleshooting the vehicle and remote control desk.
Traffic controller
The traffic controller was located in the traffic control centre (BZ-Zurich Airport) and set the routes for the shunting movement. This was the regular traffic controller responsible for shunting yard Mülligen.
HTO team
The HTO team accompanied the test candidates before, during and after the test. The team was responsible for collecting the HTO analysis.
Moderator
The moderator (SBB) accompanied the test candidates before, during and after the test. He moderated the tests at the remote control desk and had a direct connection to the people on the vehicle.

Table 3 - Description of the involved roles

4.3 Training and Instructions

All persons involved (SBB, Alstom, DLR, test candidates) received specific training for their respective roles. Prior to the tests, each test candidate was provided with documentation and operating instructions for the remote control desk. On the day of the tests, the test candidates received system instructions from SBB, DLR and Alstom. Before the official test runs, the test candidates carried out training runs.

4.4 Description of the test scenarios

The twelve selected test scenarios are described in the following table. The fulfilment criteria can be found in the detailed study by DLR (see chapter 7 - Reference).

Scenarios	**Description**
Dwarf signal in front of the vehicle tip	*The remote operator takes over control of the stationary vehicle, with the front of the vehicle behind the relevant dwarf signal so that the dwarf signal is visible.*
Dwarf signal directly at the tip of the vehicle	*The remote operator takes over control of the stationary vehicle, with the tip of the vehicle directly at the relevant dwarf signal so that the dwarf signal is not visible or only partially visible.*
Start in front of unoccupied crossing switch	*The remote operator takes over control of the stationary vehicle in front of an unoccupied crossing switch where two tracks merge into one – The remote operator might see a dwarf signal after the switch, but cannot be sure that this applies to the own track. The relevant dwarf signal is located behind the vehicle.*
No special features	*Proceed according to signals with no incidents.*
Stop before person on the track	*During the movement, there is a person on the track in front of the vehicle. At the Zurich-Mülligen shunting yard, the scenario was implemented by placing a high visibility vest over a stop signal and placing this combination on the track.*
Stop in front of a drag shoe	*During the movement, there is a drag shoe on the track in front of the vehicle.*
Dwarf signal unexpectedly switches to stop	*In this case, the route is cancelled during the movement and the dwarf signal switches back to stop. For this purpose, the traffic controller immediately sets the corresponding dwarf signal to stop after passing the preceding dwarf signal showing a proceed aspect. In this way, the remote operator cannot see the change of the preceding dwarf signal from "Proceed" to "Proceed with caution" in the camera image, so that the remote operator does not expect a signal indicating a stop.*
De-energised section	*The vehicle encounters a signal that indicates to lower the current pantograph. As an added difficulty, the signal is positioned to the right of the track so that the remote operator must recognise the arrow on the signal, which assigns the signal to its own track.*
Stop before signal	*The movement ends at the end of the set route in front of a dwarf signal indicating a stop.*
Stop in front of red stop sign	*During the movement, there is a red stop sign on the track in front of the vehicle.*
Driving up to rail vehicle (coupling)	*At the end of the movement, there is a railway vehicle on the track that the remote operator should approach as if the vehicle was going to couple.*
Stop in front of buffer stop	*At the end of the movement, there is a buffer stop on the track, which the remote operator should approach a stop within 1m (no contact between buffer stop and buffer).*

Table 4 - Description of the test scenarios

4.5 TEST BLOCKS AND SCENARIOS

The tests included one or two initial training sessions. The actual test runs only started once the test candidates felt comfortable with the test environment and the remote control desk.

Each test candidate executed several test blocks. A test block consisted of three scenarios:

Training	0	I	Signal **in front of** vehicle	II	**No specificities**	III	Stop at **signal**
Test	A	I	Signal **directly at** vehicle tip	II	Stop before **person (orange vest)** on track	III	**Non-electrified section**
	B	I	Signal **in front of** vehicle	II	Stop before **brake shoe**	III	Stop before **red stop sign** in track
	C	I	In front of **crossing switch**	II	**No specificities**	III	Stop at **buffer stop**
	D	I	Signal **in front of** vehicle	II	**No specificities**	III	**Drive up to rail vehicle** (as for coupling)
	E	I	Signal **in front of** vehicle	II	Signal **falls back to stop**	III	Stop at **signal**

Figure 10 - Test blocks

Taking into account various boundary conditions the following block sequences were carried out: ACBDE / BDECA / ECADB. Caused by operational reasons, five blocks were executed during the morning and evening sessions, four blocks were executed during the afternoon session.

The project management (SBB) coordinated the overall implementation and the operational aspects with the traffic control centre, while Alstom took over the technical assistance for the vehicle and the remote control desk.

4.5.1 Test schedule

The test runs took place from 5 February to 31 March 2024 according to the following schedule:

Basic data				Morning						Afternoon					Evening					
Date	Candidate	Time slot	Block order	Training block	Block 1	Block 2	Block 3	Block 4	Block 5	Training block	Block 1	Block 2	Block 3	Block 4	Training block	Block 1	Block 2	Block 3	Block 4	Block 5
05.02.2024	1	Morning	1	Route 0	Route A	Route C	Route B	Route D	Route E											
05.02.2024	2	Afternoon	1							Route 0	Route A	Route C	Route B							
06.02.2024	3	Morning	2	Route 0	Route B	Route D	Route E	Route C	Route A											
06.02.2024	4	Afternoon	2							Route 0	Route B	Route D	Route E							
07.02.2024	1	Evening	3												Route 0	Route E	Route C	Route A	Route D	Route B
08.02.2024	3	Evening	1												Route 0	Route A	Route C	Route B	Route D	Route E
12.02.2024	5	Morning	2	Route 0	Route B	Route D	Route E	Route C	Route A											
12.02.2024	6	Afternoon	3							Route 0	Route E	Route C	Route A							
13.02.2024	7	Morning	3	Route 0	Route E	Route C	Route A	Route D	Route B											
13.02.2024	8	Afternoon	1							Route 0	Route A	Route C	Route B							
14.02.2024	5	Evening	1												Route 0	Route A	Route C	Route B	Route D	Route E
15.02.2024	7	Evening	2												Route 0	Route B	Route D	Route E	Route C	Route A
19.02.2024	9	Morning	3	Route 0	Route E	Route C	Route A	Route D	Route B											
19.02.2024	10	Afternoon	2							Route 0	Route B	Route D	Route E	Route C						
20.02.2024	11	Morning	1	Route 0	Route A	Route C	Route B	Route D	Route E											
20.02.2024	12	Afternoon	3							Route 0	Route E	Route C	Route A	Route D						
21.02.2024	9	Evening	2												Route 0	Route B	Route D	Route E	Route C	Route A
22.02.2024	11	Evening	3												Route 0	Route E	Route A	Route D	Route B	Route C
26.02.2024	13	Morning	1	Route 0	Route A	Route C	Route B	Route D	Route E											
26.02.2024	14	Afternoon	1							Route 0	Route A	Route C	Route B	Route D						
27.02.2024	15	Morning	2	Route 0	Route B	Route D	Route E	Route C	Route A											
27.02.2024	16	Afternoon	2							Route 0	Route B	Route D	Route E	Route C						
28.02.2024	13	Evening	3												Route 0	Route C	Route E	Route A	Route D	Route B
29.02.2024	15	Evening	1												Route 0	Route C	Route A	Route B	Route D	Route E
04.03.2024	17	Morning	2	Route 0	Route B	Route D	Route E	Route C	Route A											
04.03.2024	18	Afternoon	3							Route 0	Route E	Route C	Route A	Route D						
05.03.2024	19	Morning	3	Route 0	Route E	Route C	Route A	Route D	Route B											
05.03.2024	20	Afternoon	1							Route 0	Route A	Route C	Route B	Route D						
06.03.2024	17	Evening	1												Route 0	Route C	Route A	Route B	Route D	Route E
07.03.2024	19	Evening	2												Route 0	Route C	Route B	Route D	Route E	Route A
11.03.2024	21	Morning	3	Route 0	Route E	Route C	Route A	Route D	Route B											
11.03.2024	22	Afternoon	2							Route 0	Route B	Route D	Route E	Route C						
12.03.2024	23	Morning	1	Route 0	Route A	Route C	Route B	Route D	Route E											
12.03.2024	24	Afternoon	3							Route 0	Route E	Route C	Route A	Route D						
13.03.2024	21	Evening	2												Route 0	Route C	Route B	Route D	Route E	Route A
14.03.2024	23	Evening	3												Route 0	Route C	Route E	Route A	Route D	Route B

Figure 11 - Test schedule broken down by day segment, time and test blocks

It was intended to perform the tests under varying ambient brightness conditions. However due to operational reasons, movements could only be performed during the following time slots

- from 9.30am to 3.30pm (day runs)
- from 7pm to midnight (night runs)

Figure 12 - Remote control desk at night

4.6 Process of test runs

As soon as the vehicle was ready at the starting point for the respective test case, the engine driver handed over control to the remote operator for the test run. This was followed by the static brake test via the remote control in coordination with the supervisor for test drive. After notifying readiness for travel to the traffic controller, the route was set for the test case so that the remote operator could start. The supervisor for test drive and the engine driver for test runs had the opportunity to intervene at any time and take over or stop the movement.

The engine driver/supervisor for the test run had the following two options for overriding the remote operator:
By deactivating or not activating the "illuminated pushbutton on the remote control", the remote operator could be prevented from selecting the direction of travel and disengaging the parking brake.
In critical situations, the engine driver for test runs was able to initiate an emergency brake and disconnect the locomotive from the remote control system.

Table 5 - Override options by the engine driver for test run

4.6.1 System behaviour in the event of a connection failure

System behaviour after detection of a connection loss (>1 second):
Flashing of the red "illuminated pushbutton on the remote control" (on the locomotive).
Traction cut off (on the locomotive).
Sounding of an audio alarm (on the locomotive).
Indication on the monitoring screen (on the remote control desk).
When the connection was re-established within 3 seconds:
Steady light of the red "illuminated pushbutton of the remote control" (on the locomotive).
Stopping of the audio alarm (on the locomotive).
Traction is taken into account immediately (on the locomotive).
Normal image on the monitoring screen (on the remote control desk).
When the connection was not re-established within 3 seconds:
Triggering a service break by automatically lowering the main line pressure to 3 bar (on the locomotive).
Correct connection / connection failure:
It was displayed to the remote operator on the monitoring screen (see below) with a green "Safe to roll" area, if the connection was correct established (on the remote control desk). *On the vehicle the bush pushbutton (see* Figure 14*) was illuminated continuously when the connection was correctly established.*
If the connection failed or the latency was too high, it was indicated to the remote operator on the monitoring screen (see below) by displaying red "Integrity issue" bars (on the remote control desk). *The remote operator had to inform the personnel on the locomotive in this case.*

Table 6 - System behaviour in case of a connection failure

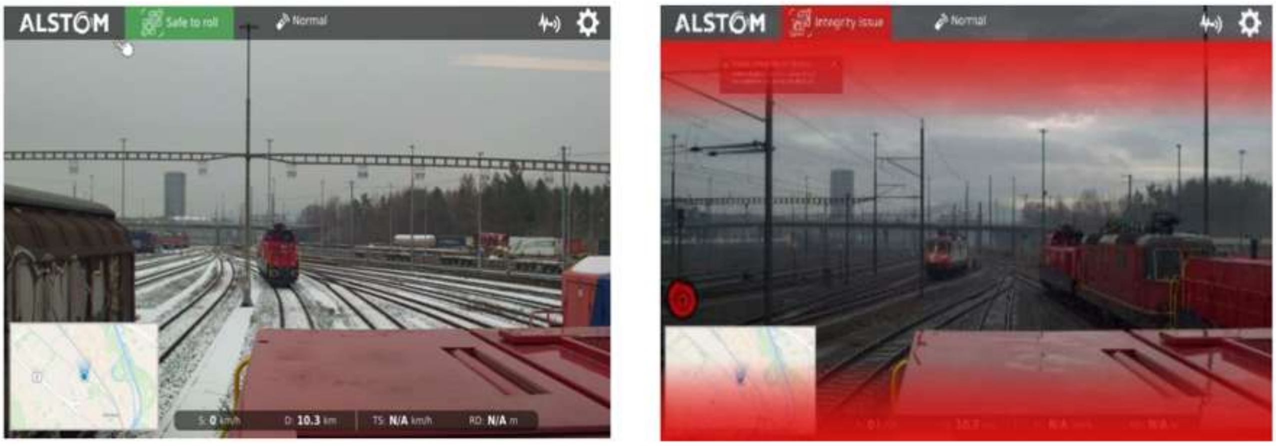


Figure 13 - Monitoring screen with established connection / connection problems

Figure 14 - Illuminated pushbutton on the remote control

5 ANALYSIS

All observations made by the entire test team during the test runs were included in the analysis and are detailed in the respective sections.

5.1 HUMANS, TECHNOLOGY AND ORGANISATION

The HTO analysis was carried out by the project partner DLR. The methodology used for the study and for the assessment, along with all further information are described in detail in in the HTO analyses on remote shunting operations (see chapter 7 - Reference).
Total number and allocation of blocks executed throughout the entire test period:
A: 32 / B: 32 / C: 35 / D: 33 / E: 31

The following chapters contain an extract of the key findings.

5.1.1 Success of task fulfilment

Almost all test scenarios/tasks were successfully completed (see Figure 15). A significant exception to this was the detection of the drag shoe, which proved to be difficult with the used remote control system and was only successfully completed in a quarter of all cases. A second major exception is the exact determination of the vehicle location within the task "Start in front of unoccupied crossing switch", which could only be successfully completed in two thirds of all cases. The combination of the "size of the object" and the "still suboptimal image quality" lead to a poor detection of small objects. The scenarios "Dwarf signal in front of the vehicle tip", "No special features", "Stop in front of buffer stop" and "Driving up to rail vehicle (coupling)" were mostly resolved successfully (between 91% and 97%).

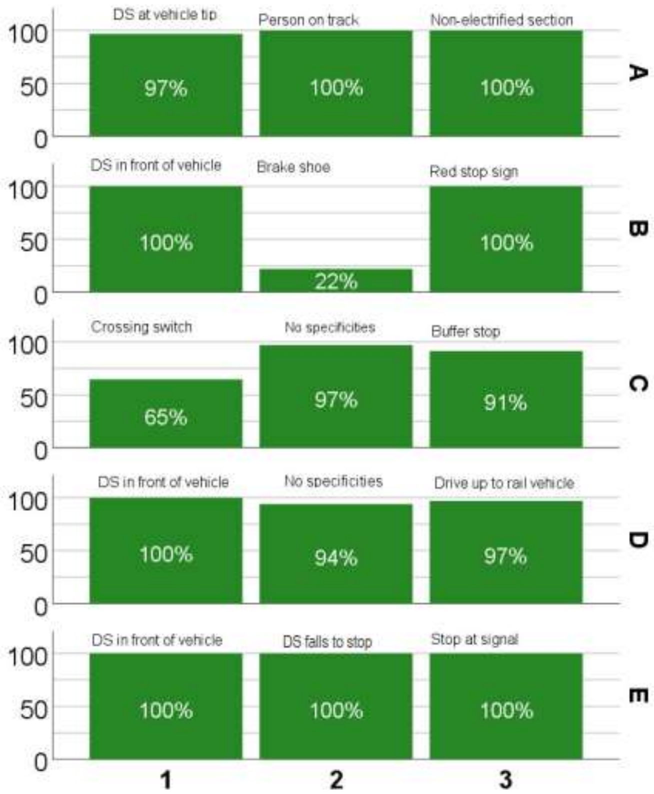


Figure 15 - Results by block and scenario

The successful task completion was also compared between day and night sessions (see Figure 16). Note that the day session was consistently the first interaction with the system and the night session was the second one (due to safety considerations).

Almost all tasks were successfully completed during the night session by all participants. An exception remains the detection of the drag shoe, where the performance at night was even worse than during the day session (17% vs. 25%).

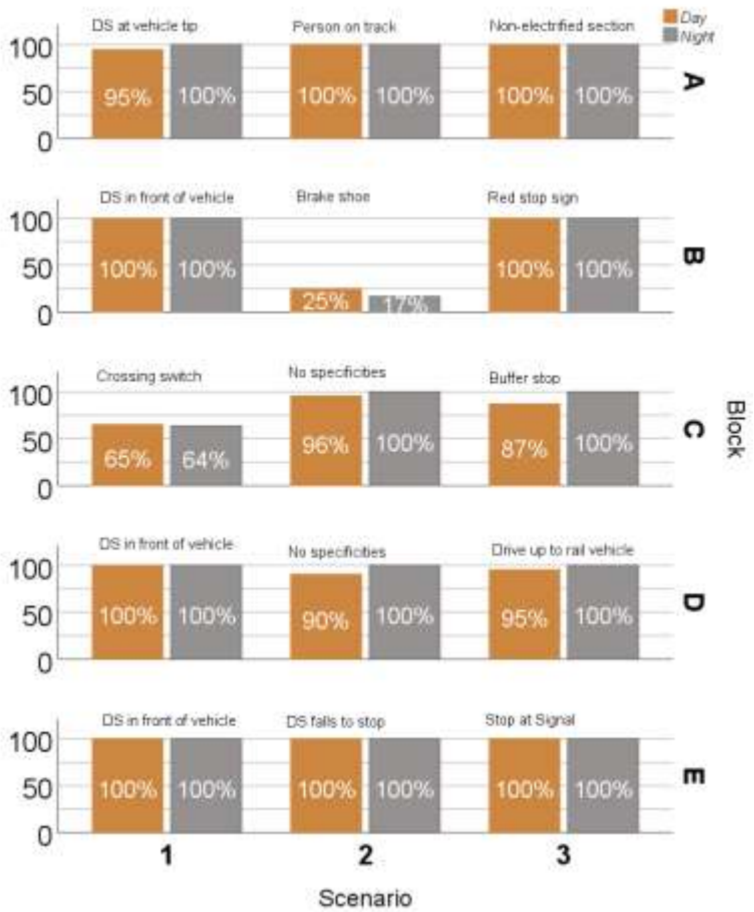


Figure 16 - Successfully resolved tasks compared day vs. night session

Note that only the data of the 24 drivers who completed the morning and the evening session are included for Figure 16 and Figure 17.

The following table indicates a selection of additional relevant findings from the test runs:

Additional relevant findings from the test runs
The signal colours were sometimes displayed incorrectly on the monitors on the remote control desk. For example, the main signal aspect "Stop" was displayed white instead of red. In addition, the white lights of the dwarf signals sometimes appeared in colour.
Additional points of light were observed, which were caused by reflections, e.g. caused by wet railroad sleeper.
Detection of the route (position of crossing switch) especially during the night session, was found to be challenging.
In particular during the night session, a visual "bunching" of individual lights was observed, which led to a delayed detection of the aspect of the signal indicated on dwarf signals.

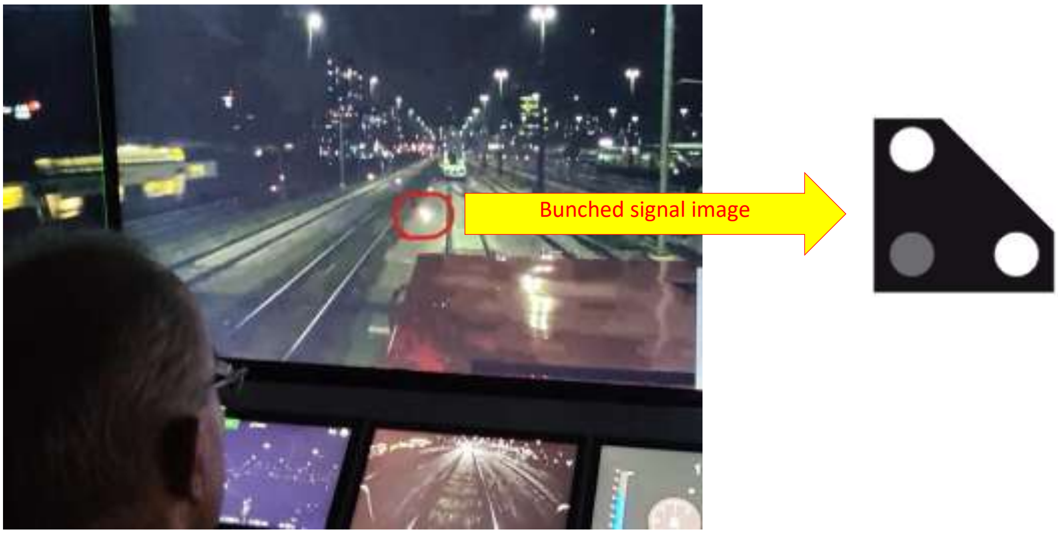


Table 7 - Additional relevant findings from the test runs

5.1.2 Distances until test object detection

For scenarios A-2 (“Stop before person on the track”), B-2 (“Stop in front of a drag shoe”), B-3 (“Red stop sign”) and E-2 (“Dwarf unexpectedly switches to stop”), the distance to the respective object at the moment of detection was determined. The evaluation refers only to cases where the object was successfully detected by the remote operator before the engine driver for test run intervened. Therefore, the evaluation of the distance for the drag shoe was only possible in 22% of all cases. The measured distance varied substantially. The results range from approx. max. 192m (A-2: “Stop before person on the track”) to a minimum of approx. 9m (B-2: “Stop in front of a drag shoe”).

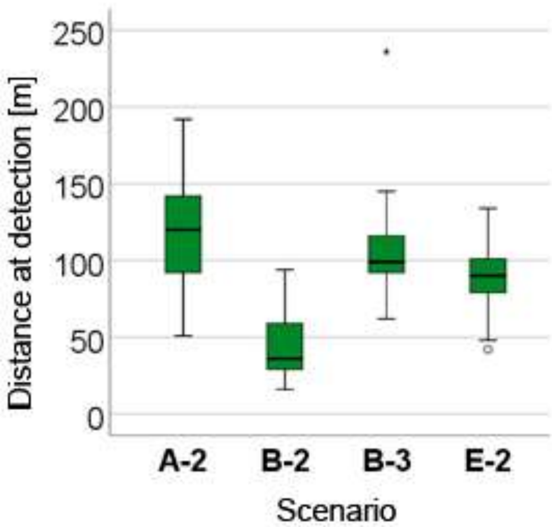


Figure 17 - Distance to the object (day and night)

The stopping distance to the buffer stop was maintained very well despite the lack of driving feel and latency. This distance varied from a few centimetres to several metres. The difference between the day and night sessions was only marginally, although it should be noted that the diagram only includes the successful executions where the safety driver on the locomotive did not intervene (87% during the day session, 100% during the night session - see Figure 18). It should be noted that the night session was always the second interaction with the system.

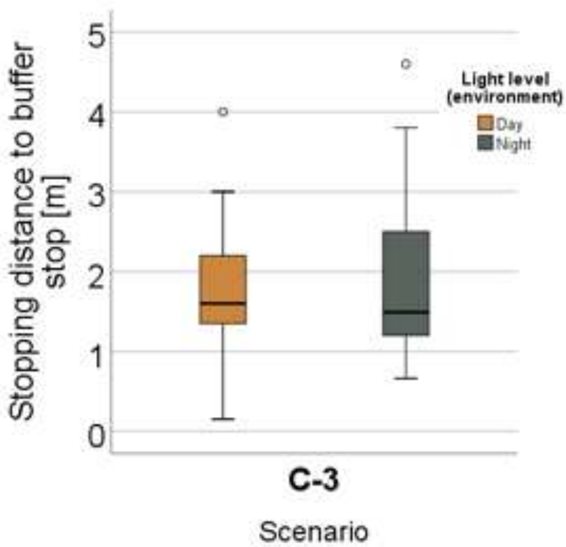


Figure 18 - Distance to the buffer stop after stopping

5.1.3 Day and night runs

Comparing day and night runs, only minimal differences were found. Generally, all test objects tended to be recognised better during the day session. On the other hand, red stop signs were easier to recognise at night for the participants. This was caused by the light reflection of the sign, allowing it to be seen earlier. The detection of drag shoe during the night session was rated as very difficult. It should be noted that in some cases the drag shoe was not recognised at all and therefore the designated personnel on the locomotive had to intervene.

The following figure indicates only the results (comparison day/night) from the participants who executed both sessions.

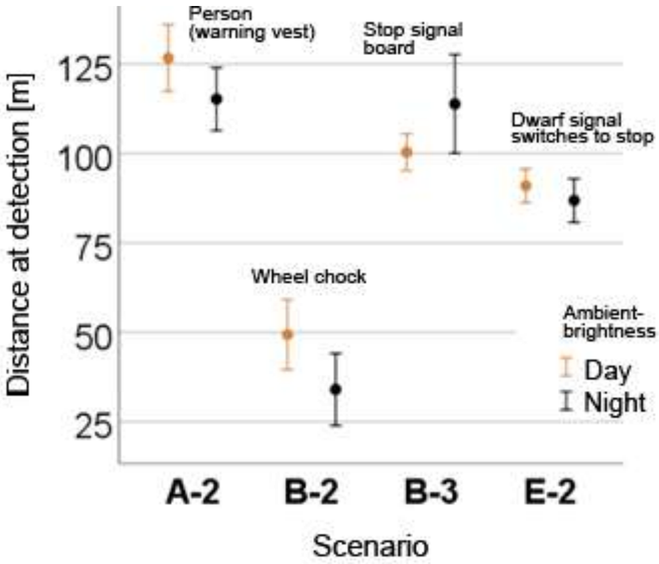


Figure 19 - Distance for detecting people / objects during the day and night session

5.1.4 Task difficulty

The test candidates rated the completion of shunting tasks with remote control as more difficult than controlling the manoeuvre directly on the locomotive. Approaching another railway vehicle (coupling scenario) as well as detecting small objects (drag shoe) were rated to be the most difficult.

5.1.5 Workload

The overall workload of the test candidates measured with the NASA-TLX (Hart & Staveland, 1988) was continuously in the mid range. When analysing the various aspects (mental and physical demands as well as time pressure), the greatest load was found in the "mental demand" aspect.

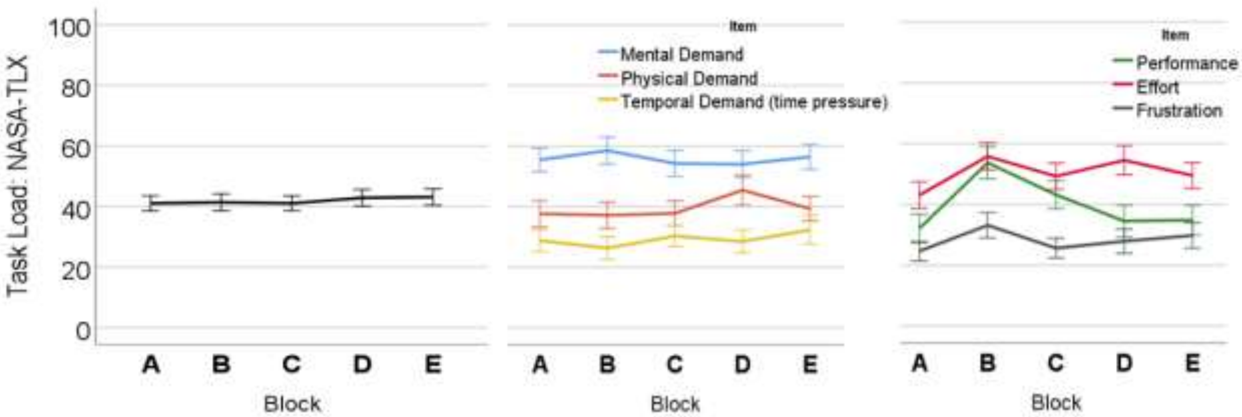


Figure 20 - Total workload during the run

5.1.6 Situational awareness

"Situational awareness" refers to the perception and understanding of all relevant information in the environment that is required to make decisions based on facts. Considering this aspect, the remote operators were interviewed using selected items from SART (Situation Awareness Rating Technique; Selcon & Taylor, 1990; Taylor, 1989). Both alertness and allocation of attention (paying attention to numerous aspects of the situation at the same time) were rated and experienced as very high.

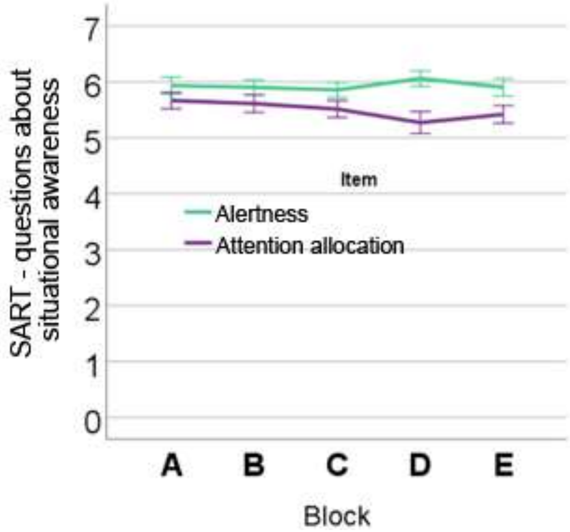


Figure 21 - Situational awareness

5.1.7 System usability

The SUS (System Usability Scale; Brooke, 1996) was used to measure the system usability. The rating scale ranges from 0 to 100, with higher values indicating better usability. An average SUS score is around 68.

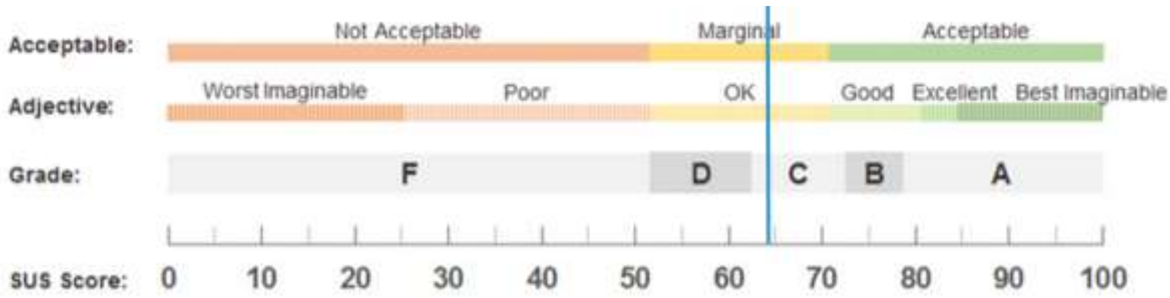


Figure 22 - SUS score

The mean overall SUS score for the prototypical workplace was 64.3, an average score in this case (the scores of the individual remote operators ranged from 35.0 to 87.5). Overall, the result can be interpreted as mediocre or adequate.

5.1.8 User acceptance

The assessment of user acceptance was recorded using the van der Laan scale. Values ranging from -2 to 2 were assigned to the answers, with a value greater than 0 indicating a positive user acceptance. The user acceptance remained neutral for the used system.

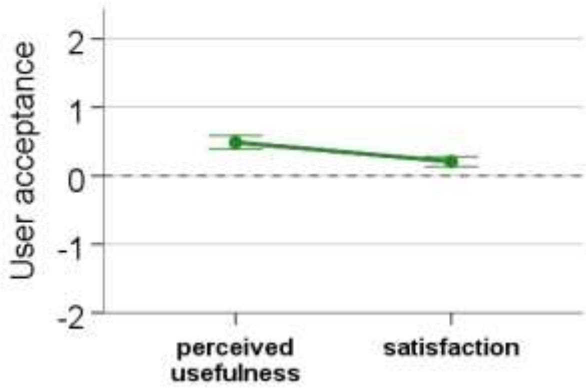


Figure 23 - User acceptance

5.1.9 Fatigue

The fatigue at the beginning and end of the session was also analysed using the Karolinska Sleepiness Scale (KSS, Akerstedt & Gillberg, 1990). On average across all sessions, the subjective fatigue after the test session was around one point higher on the scale compared to the beginning. Overall, the fatigue level remained low.

5.2 OTHER FEEDBACK FROM THE TEST CANDIDATES

5.2.1 General

Most of the test candidates were amazed about today's technical possibilities. Most of the test candidates could imagine using a remote control system in the future. However, the current state of the system is not yet seen as ready for use. The topic regarding changing of workplace (fear of job loss) was critically questioned.

5.2.2 Safety

Further concerns were raised regarding changed perceived sense of safety (e.g. due to the limited field of vision and image resolution). The study clearly demonstrated that the image quality of the remote desk is crucial for perceived reliability, availability, and safety of the system. The lack of surrounding visibility or additional information (e.g., details about downhill/uphill gradients) was noted by the test candidates. Depending on the situation, the system latency is perceived as a safety-critical factor.

5.2.3 Precision

The control of the system was rated to be suitable and allowed a precise movement of the locomotive. The subjectively perceived operator control of the system was rated better for short distances. The vehicle was never driven with a trailing load during the tests. Caused by a delayed application of the brake when manoeuvring with a trailing load, a reduced latency is demanded.

Vehicle movements controlled from the driver's cab of the vehicle provide a better surrounding view due to the side windows and the ability to move inside the locomotive (e.g. checking dwarf signals). The acoustic feedback in the driver's cab (e.g. when releasing the brake or when coupling) was also rated as useful.

5.2.4 Efficiency

The test candidates estimated in some cases the speed of the remote-controlled movement up to 50% slower compared to an on-site movement. A reason for that was the more defensive driving behaviour. During night driving, the speed was even lower due to restricted visibility.

Efficiency also decreased when permission to proceed had to be requested by the traffic controller when starting up in front of unoccupied crossing switch and the dwarf signal was located outside the field of vision. With on-site controlled movements, the test candidates rated it easier to get an overall picture of the surroundings.

5.2.5 Changes to the career profile and work culture

The feedback regarding the impact of remote control on changing the work culture varied and ranged from enthusiasm to scepticism. The responses indicated that the test candidates acknowledge that changes are inevitable. The perception between older and younger engine drivers also differed. It was noted that older colleagues tend to find it more difficult to deal with changes in the career profile. Individual test candidates, particularly those used to play computer games, rated remote control operation as less of a threat to their job compared to older test candidates.

An alternating model that combines working days with remote control and working days with manual driving on the locomotive would be desirable. The loss of social contact due to remote working (communication and interaction between employees) was mentioned. Some test candidates expressed a desire for remote control offices with multiple workstations. On the one hand, they could obtain a second opinion in the event of uncertainties and on the other hand to have social interaction during breaks.

5.2.6 Areas of application/potential

When analysing potential areas of application, the feedback varied and was often contradictory, making the topic highly subjective and difficult to interpret. As a result, it was not possible to draw any definitive conclusions.

5.2.7 Suggestions for improvement

During and after the test session, the test teams and test candidates identified and discussed numerous suggestions for improvement. Some of the relevant suggestions for improvement are summarised below and were divided into categories. Further information can be found in 7 - Reference.

Camera position and image resolution
Higher image resolution and quality.
Larger camera angles depending on vehicle type.
Additional rear-view camera (e.g. verifying previous dwarf signal).
Coherent image (circumferential view).
For movements during the night, the camera should be placed near the headlight to ensure good illumination of the field of vision and to reduce shadows.
Transmission of information
Bi-directional audio transmission.
Object detection with perception system: For example warning when drag shoes and people are detected.
Speed indicator centrally positioned on the screen
Structure of the workplace / cooperation
Dynamic remote workstation: Simulation of movements or haptic feedback on the master controller in the event of wheel slip.
Creating redundancy through teamwork with multiple workstations in the remote control center.
Training
Future remote operators must receive specific training: • *Develop an understanding of the technical system and processes (remote control).* • *Build expertise at the remote control desk.* • *Gain experience at the remote control desk and in real operational scenarios.*

Table 8 - Suggestions for improvement reported by the test candidates

5.3 TECHNICAL PROPERTIES

This section analyses the technical properties and provides further insights from the observations made during the test.

5.3.1 System description

The technical system (equipment on the vehicle and on the remote control desk) performed reliable after the trial phase. There were no long interruptions or defects that made it impossible to carry out the tests. The image transmitted to the remote operator was adequate for the tests, but not sufficient for a commercial application. The equipment of the remote control desk was reduced to a minimum.

The remote operator had no interaction with any supervision device (e.g. vigilance system) on the locomotive. During the test, these systems were operated by the engine drivers for test runs.

All tests were conducted as planned, and there was no need to postpone any sessions. It is important to emphasize that no safety-critical incidents occurred and safety was always ensured for all parties involved. No incidents related to train operation were reported and cooperation among the various parties was consistently smooth.

5.3.2 Ergonomics, screens and control

5.3.2.1 Arrangement

The test candidates generally perceived the arrangement of the screens and the control as good.

Figure 24 - Remote control desk

5.3.2.2 Speed indicator

Due to the lack of driving feel, the speed indicator is crucial for remote control operation. The test runs showed that the speed indicator should be digital and show tenths of a kilometre per hour to enable early detection of speed changes, especially at lower speed (under 40km/h). This also aids in estimating the slope of the track, approaching obstacles precisely and immediately detecting unintentional rolling. A conceivable option would be a combined analogue/digital display.

The trial phase showed that the speed should also be visible in the field of vision. The display was therefore integrated into the central panoramic monitor (see Figure 25).

Figure 25 - Digital speed indicator with tenths of kilometre per hour

5.3.2.3 Wheel slip and wheel slide feedback

In addition to the wheel slip indicator lamp, a shaker would be conceivable on the master controller to provide feedback in the event of wheel slip or wheel slide.

5.3.2.4 Acoustic feedback and intercom connection

The transmission of the acoustics from the driver's cab to the remote control desk is desired. An additional improvement would be to provide a possibility to interact with the on-site staff allowing for feedback on hand signals and acknowledgment that individuals have been noticed.

Engine drivers are used to interacting with other employees during operation (e.g. oncoming engine drivers, construction workers on other tracks, shunting personnel in the track area, etc.). Apart from using warning signals with the horn, there was no way to interact with the people in the surrounding area of the manoeuvre.

It was also noted that an intercom connection to staff on the track would be beneficial in certain situations.

Remark: At the beginning of the SBB demonstrator, the ambient acoustic from the driver's cab (locomotive) was transmitted to the remote control desk. Interference from the warning light on the locomotive (visual warning for people along the track) to the microphones impaired the quality of the acoustics at the remote desk. As the transmitted quality of the ambient noise was disruptive, the acoustic feedback was not used.

5.3.2.5 Master controller and brake lever

It was recommended that the master controller and brake lever should remain in the selected position after releasing the lever and not return to the neutral position when released (as on the remote desk) as locomotive drivers are used to this from other vehicles.

5.3.2.6 Target values

With the display used, the tractive or braking force (target value) requested by the remote operator was not displayed. Only the actual values of the tractive or braking force were available. Identical or similar target value indications to those in the driver's cab on the vehicle are desirable.

5.3.2.7 User friendliness of remote control desk

User friendliness could be improved if there were at least the same number of control levers for the "drive and brake" function (vehicle and remote control desk as identical as possible). For example, the remote control desk did not have a lever to control the main line pressure of the indirect brake, which was unusual for the remote operators. The control of the main line pressure was not required for the test without trailing load.

5.3.2.8 Perception/distance estimation

Estimating the distance to obstacles is challenging and requires experience with the different cameras for close and normal range. Possible sensors for displaying distances to obstacles (vehicles, drag shoes on the track, buffer stop, etc.) or signals could be useful. Front cameras with adaptive cornering and zoom function would be a way to improve the system. Additional rear-view cameras for consulting the previous dwarf signal would be another possibility. Cameras for transmitting a bird's eye view (overview of the surroundings) could also support the remote operator.
The minimum values defined for detection of obstacles and signals of 100m in good weather and visibility conditions and a maximum speed of 30km/h were confirmed with the test runs. The detection of the switch position based on the blades at the distance of 50m defined in the call for tenders was rather short. A distance of 100m is recommended.

5.3.2.9 Position detection

The position detection using Google Maps worked proper. However, this position detection option did not meet the requirements of a remote control system The map only provides a rough outline of the railway system, making it useful primarily for general orientation regarding the vehicle's location. Due to the GPS technology used, the direction of travel is only identifiable when the vehicle is moving. While clarifying the vehicle's exact position, misunderstandings could occur if the remote operator and the traffic controller assume an incorrect position and/or a different direction of travel of the vehicle.

Sources of misunderstandings:

- Indistinctly visible track numbering or no view of track numbering by the remote operator.
- Confirmation by the traffic controller of a location transmitted incorrectly by the remote operator due to another shunting movement occupying the track.

5.3.2.10 Communications between traffic controller and remote operator

In general, operation with "remote control from a control centre" raises the demands for flawless communication among all participants involved. For example, it is crucial that the remote operator specifies the location of the remote-controlled vehicle rather than the location of the remote desk.

5.3.3 Camera system

5.3.3.1 Panoramic view camera

The resolution of the camera image was found to be insufficient and the image quality deteriorated further under dark and poor weather conditions.

It was mentioned that the side cameras could be dispensed if necessary during the movement, as the remote operator primarily focuses on the central screen during the movement. However, the two side screens still contribute to a more realistic experience. To reduce the amount of data transmitted, their resolution could be lower than the central screen. This still needs to be investigated.
The images from the panoramic monitors were also very helpful for orientation and position determination when stationary, enabling the remote operator to better detect the vehicle's surroundings (e.g. switches, signals and track designations). This supported the remote operators to determine the position of the vehicle.

5.3.3.2 Coupling area (Berne Space)

The video image from the front camera / near field camera (Berne Space) was very useful when approaching objects or obstacles (buffer stop, drag shoe, signals or other vehicles).

This view was also used to detect signals outside the detection range of the three panoramic view cameras. Especially for the detection of dwarf signals, which were located right next to the tip of the vehicle.

Distance estimation could be improved by indicating the distance with an accuracy of up to one meter on the image from this camera.

5.3.3.3 Field of view

The cameras used had a limited field of view. As a result, in some cases the remote operator had difficulties to check the locomotive's surroundings (e.g. recognising the previous dwarf signal, the current pantograph, the track designations above the tracks, etc.).

5.3.3.4 Lighting conditions

The camera system used demonstrated that the latest-generation cameras are unsuitable for further applications. Systems with better dynamic adaptation to varying lighting conditions should be used instead.

Note: The tests were carried out with two different parametrised camera configurations for day and night). The switchover had to be performed manually.

5.3.3.5 Blind spot at the tip of the vehicle

For safe operation, it must be possible to detect dwarf signals at the tip of the vehicle from the remote desk. Since the remote operator cannot look out of the windows to assess the situation, additional cameras are recommended for the blind spot area. This ensures that dwarf signals located directly next to the tip of the vehicle are not overlooked. It is important to note that in Switzerland, dwarf signals are typically positioned on the left, and rarely on the right.

"Blind spot cameras" could be used to ensure that the remote operator does not make any movements without authorisation because of overlooking signals at the tip of the vehicle. Unauthorised movements mean a high potential risk of a collision. In this context, it was not studied whether cameras located on both sides, laterally behind the tip of the vehicle, which transmit the blind spots at both ends of the vehicle to the remote workstation, would help the remote operator detect dwarf signals located directly at the tip of the vehicle. The camera system used was sufficient to detect the signals at the tip of train during the test runs.
For future applications, the topic regarding the blind spot needs to be investigated more in detail.

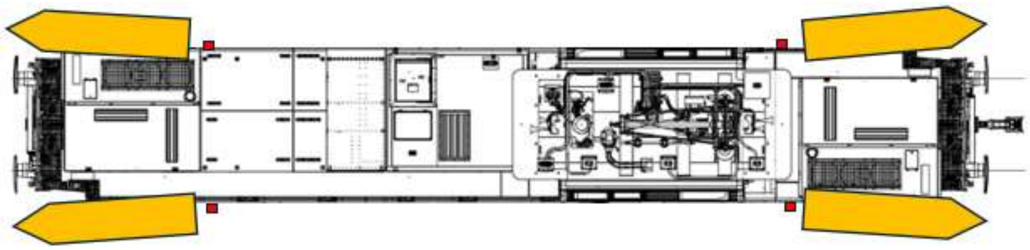


Figure 26 - Sketch of possible camera positions for monitoring blind spots

5.3.3.6 Further findings regarding the camera system

Depending on the application (e.g. regular shunting operations) a perception system for signal and obstacle detection could enhance the user-friendliness and safety of the system. This refers to the linking of data from multiple sensors to obtain better information (sensor fusion).

5.3.4 Localisation

Localisation systems are essential for displaying the vehicle's position and viewing direction on a live track or interlocking plan, making it easier for the remote operator to pinpoint the vehicle's location. This is especially important if the remote operator has limited knowledge of the area.

5.3.5 System behaviour in response to a connection loss

The system behaviour in response to a connection loss must be defined.

5.3.5.1 Latency

The intended maximum latency value was 500ms while the actual latency ranged between 500ms and 750ms. The remote operators noticed a certain delay in the system but were able to adapt and adjust their operations accordingly.

It was found that a latency value of 500ms is adequate for remote control in the given environment and under the given speed restrictions, although a lower latency is desirable. However, the image quality must meet the requirements of the respective application. Reducing the latency to below 500ms should not compromise image quality.

To prevent the remote operator from being surprised when operating the vehicle (response behaviour), the latency must not be subject to pronounced fluctuations and must therefore be as constant as possible. The controllability of the remote-controlled movement therefore also depends on a constant latency.

5.3.5.2 Usability

The remote operators went through a steep learning curve and quickly became familiar with the remote control desk. For the majority of test candidates, 1-2 training runs lasting around 30 minutes were sufficient. Most participants were able to handle the tasks well. Additionally, the test candidates had prior experience working with simulators, which they could adapt to the remote desk.

5.4 Additional tests - ETCS shunting signal

Additional test runs were carried out with an ETCS shunting signal (dwarf signal with blue lamps).

Figure 27 - ETCS shunting signal in "Stop" position

For this purpose, an ETCS shunting signal was positioned in the track area and modified with manual switching box (independent of interlocking). All signal aspects (“Proceed”, “Proceed with caution”, “Stop”) could be selected. The recognisability of the individual signal aspects at different distances was tested from the remote operator's perspective. It was observed that the camera recognised the signal image similar as with common dwarf signals (blurring/clumping). Additionally, the blue colour of the lenses on the ETCS shunting signal was not accurately reproduced, often appearing white instead of blue.

The following illustration shows the ETCS shunting stop signal as displayed on the monitor of the remote control desk. The lens colour (blue) was not accurately reproduced. For comparison, the image of the actual ETCS shunting signal is shown in red (see Figure 28).

Figure 28 - View of ETCS shunting signal in “Stop” position on the remote desk

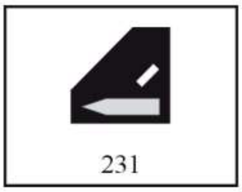
5.5 Implementation recommendations

The following implementation recommendations were derived from the test runs conducted within the SBB demonstrator. It is important to note that the challenges are complex and vary depending on the application of remote operation. Therefore, the requirements must be developed and tailored specifically.

Examples of possible application for remote operation:

- Fallback level (degraded mode) of fully automated operation
- Regular remote-controlled operation such as:
  - Train or shunting movements in context with train preparation (movement from siding to platform).
  - Stabling movements (movement from platform to siding).
  - Movements in context with train washing installation.
  - Movement in context with maintenance and service facilities / depot manoeuvres.
  - Movement in context with construction site.
  - Movement in context with of supporting other vehicles (e.g. to evacuate broken-down trains).

List of implementation recommendations

ID	Description
1.	Use driving screens with a wide field of vision (panoramic view) to create a realistic "visual" driving feel and for an easier determination of the position.
2.	High image resolution and quality to provide the surroundings and the signal colours on the monitors realistically (in all ambient conditions such as day, night, backlighting, heavy rain, fog, snow, frost, extreme heat, etc.) is needed. While stationary, high image resolution quality must be guaranteed on all monitors. Especially for recognising details for localisation (signal designations, track numbers, etc.). *NB: To reduce the amount of data to be transmitted (latency optimisation), the resolution of all monitors not pointing directly in the direction of travel could be lowered during the movement.*
3.	The system must ensure that the central monitor of the remote control desk is able to display small obstacles such as drag shoes and positions of the switch at a distance of 100m.
4.	Cameras for close, medium and long range should be provided. If necessary, with zoom function and swivelling cameras for positioning. *Note on positioning: The track numbers are shown above the tracks in the parking/shunting area. An engine driver on site can verify these signs by "looking out of the open window" or "getting off the vehicle on site". It is crucial for the remote operator to be able to recognise these track numbers in case there is no other reliable localisation available.*
5.	Specific near field cameras for transmitting the coupling area (Berne Space) on the remote control desk are recommended.
6.	Rear-view cameras for consulting the dwarf signal behind are recommended. Rückseite der Zwergsignale  Auf der Rückseite der Zwergsignale weist ein aufgemalter weisser Pfeil auf das zugehörige Gleis. Zeigt das Zwergsignal *Fahrt* oder *Fahrt mit Vorsicht,* ist dies an einem weissen schrägen Lichtstreifen (Rücklicht) erkennbar. Source: FDV 742.173.001 / 1. Juli 2024 / R 300.2
7.	Blind spots at the tip of the vehicle must be avoided. *NB: Authorisation to proceed is given by means of light signals. These signals may be located directly alongside the tip of the vehicle and must be always recognised.*

8.	When positioning the cameras, the place of the headlight and its light cone (for low beam and high beam) must be considered. The aim is to make optimum use of the available light sources to improve the image quality.
9.	For regular remote-controlled applications (outside of the degraded mode), additional sensors must be used for automated signal and object detection to increase safety. Depending on the application, with or without integration into the vehicle electronics / vehicle control system.
10.	A maximum latency of 500ms should be aimed for images during the movement. A shorter latency is desirable but must not lead to unacceptably lower image quality. For the images of the surroundings for positioning when stationary, the latency can also be higher. To prevent the remote operator from being surprised when operating the vehicle (response behaviour), the latency must not be subject to pronounced fluctuations and must therefore be as constant as possible. A concept must be developed for the system behaviour if the latency is too high. The remote operator must be able to always recognise excessive or non-constant / fluctuating latency.
11.	If the connection fails, the remote-controlled movement must be stopped automatically and brought to a safe state after standstill. A concept must be developed for the system behaviour if the connection is lost. The remote operator must be able to always recognise a connection failure.
12.	The remote operator must be able to control the parking brake. The minimum holding force required for the relevant grade must be achieved, as drag shoes can only be used when personnel are present at the vehicle. NB: In accordance with the FDV, it must be possible to secure the vehicle anytime without the use of compressed air.
13.	The speed indicator on the remote control desk should be indicated as analogue and digital format (similar or identical to the ETCS DMI). In addition, a digital speed indicator with increments of a tenth of a kilometre should be in the centre of the remote operator's field of vision without superimposing information on the surroundings (head-up display effect). NB: The digital speed indicator with tenths of a kilometre display (0.1km/h) is used so that speed changes can be detected early (estimation of the track grade, for precise approach to obstacles or immediate detection of unintentional rolling...).
14.	Remote control operation should only be terminated when the parking brake is applied.
15.	A concept must be developed for implementing the remote operator's vigilance control system.
16.	Distance feedback in relation to the track ahead. For example:

	• *Acoustic distance feedback (e.g. the smaller the distance to the obstacle, the more intensive is the feedback).* • *Display of a metre scale on the central main monitor (e.g. up to 20m).*
17.	Feedback on the remote control desk of the track grade (gradient) at the vehicle's current location. *Example: with rising gradient + x‰ or with falling gradient - x‰*
18.	Tactile feedback of "wheel slip or wheel slide" on the master controller and brake lever. *NB: For example, shaking/vibration of the master controller and brake lever.*
19.	Transmission of the acoustics from the driver's cab and the ambient noise outside the vehicle to the remote operator desk. *Example: Hearing the pneumatic "hissing" during the brake release process. Transmission of an acoustic warning signal outside the vehicle (hearing an acoustic signal from the train crew outside the vehicles, e.g. stop signal indicated as "three short whistles").*
20.	Project specific intercom connection to personnel along the trackside.
21.	In addition to an acoustic communication option, the waving of the engine driver (e.g. as confirmation that staff in the track area have been noticed) should be replaced by another (technical) method.
22.	The tractive and braking force should be displayed on the remote control desk. It must be ensured that the actual and target values are indicated.
23.	A speed limit is recommended when approaching other objects (e.g. vehicles). With the throttle in the "Zero (0km/h)" position, the target speed is set to 1km/h. *NB: This prevents excessive speed in the event of delayed execution of movement commands (latency).*
24.	Display of the exact positioning and orientation of the vehicle on an interlocking plan with indication of the direction of view of the remote operator so that the remote operator can recognise the direction of travel "forwards". *NB: The remote operator should be able to obtain an overview of the signalling at the vehicle location and the direction of travel "forwards" of the remote-controlled movement.*
25.	It should be ensured that the connection to the vehicle is seamless when switching to a different radio network. A connection failure when switching to a different radio network should be displayed to the remote operator. The remote operator should also be notified of any connection failures.
26.	The remote operator must be specifically instructed and trained in the technical and procedural aspects of "remote control". A concept must be developed for this purpose. This must also include the training of the other participants involved in the process (traffic controllers, shunting staff on trackside, staff for train preparation, etc.).

27.	Several redundant remote control workstations should be provided in a remote control centre. Comments: This ensures technical and personnel redundancies (system/people) on the one hand, but also enables a "dual control principle" in unclear situations (process) on the other hand. In addition, contact with colleagues could be maintained and the feeling of loneliness reduced. Possible disadvantage: Loss of concentration due to distraction from colleagues.
28.	The remote operator should be able to take a break between two consecutive remote-controlled movements. This enables the remote operator to get along easier with the new situation.
29.	The procedure in situations requiring the presence of personnel on site (external check of the vehicle, emergencies, actions on the vehicle, etc.) must be clearly defined. This also includes the check on switches according to the FDV (position of the switch, foreign objects, etc.) or the determination of the completeness of a movement on behalf of the traffic controller. Safety must be guaranteed at all time and the continuation of operation must be ensured.
30.	The handling of incidents/irregularities (e.g. accident, derailment, collision, trailing of switches) must also be ensured during operation with remote control. The processes affected must be adapted accordingly (e.g. clarifying the situation on site, securing train data, etc.).
31.	It is recommended that remotely controlled vehicles are clearly marked on the outside. *NB: If vehicles are remotely controlled, they may start to drive unexpectedly for staff in the track area. Therefore, marking (e.g. warning lights on the vehicle) would be useful.*
32.	*Traffic controllers should be able to recognise on their workstation that a vehicle is being remotely controlled.*

Table 9 - Implementation recommendations

6 CONCLUSIONS

The SBB demonstrator was successfully conducted in relation to Task 38.7 – Moving a train within a yard by remote control (shunting). It highlighted both the opportunities and possibilities, as well as their limitations.

The SBB demonstrator has shown that remote operation within shunting area with regards to HTO is applicable. The test with 24 different test candidates showed that such a system can be used after a relatively short acclimatization period. Almost all complex tasks were completed with a high degree of success.

The configuration for a remote controlled desk depends strongly on the specific use case. The developed implementation recommendations are valuable in this regard and can be incorporated into future applications.

The technical implementation needs to be optimized to ensure efficient and safe operation. For example, the recognizability of signals, position of the switch and obstacles (e.g. drag shoes) at a speed up to 30km/h should be ensured over a minimum distance of 100m. Or that shunting tasks at speeds up to 30km/h are manageable with a latency around 500ms with a maximum up to 750ms.

The results demonstrate the potential of the remote driving technology for shunting operations, but future work is recommended on specific scenarios and operating conditions, including but not limited to:

- Introducing a trailing load to validate traction, braking, and overall train handling under realistic mass conditions.
- Conducting degraded communications tests. This could include packet loss, latency spikes and variations, jitter, etc. to verify failsafe behaviour, fallback command paths, and controlled safe stop.
- In a further trial, the opportunity of using perception systems should be considered, especially including obstacle and person detection as well as track and level-crossing monitoring to strengthen situational awareness and automate hazard alerts.
- Cyber security related topics

Based on these findings, further remote operation systems can be enhanced and optimised.

7 REFERENCE

SBB commissioned DLR to conduct out the HTO study. The study was carried out by the department of "Design and Evaluation of Mobility Solutions" of DLR's Institute of Transport System. It was decided to publish the study, as it contains valuable insights for future remote operation applications. The study can be found here:

HTO ANALYSIS ON REMOTE SHUNTING OPERATION - Final report
Annika Dreßler, Niels Brandenburger, Malte Petersen, Alexandra König
DLR (2025)

Link: https://elib.dlr.de/216589/