
ATO2Basic Phase 2 Final Report

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Change history

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X.3	23.11.2020	Jens Nolte	I-NAT-SR40-ATO Siemens Mobility	Final draft for external review	Approved
1.0	01.12.2020	Jens Nolte	I-NAT-SR40-ATO	Initial edition for publication	Approved

Glossary

ATO Disengaging (DE)	An ATO-OBU operating mode, equivalent to "transition from active to inactive state". From ATO
ATO Engaged (EG)	An ATO-OBU operating mode, equivalent to "ATO active"
ATO Ready (RE)	An ATO-OBU operating mode, equivalent to "ATO not active, but can be activated"
ATO-OBU	Automatic Train Operation – On Board Unit (in RCA: ATO-AV)
ATO-TS	Automatic Train Operation – Trackside (in RCA: ATO-AT)
DCS	Data Collection System (central SBB system from which the energy data was obtained)
DDS	Data Distribution Service (vehicle control technology data storage)
DMI	Driver Machine Interface
EMS	Energy Meter System
EoA	End of Movement Authority – End of the ETCS movement authority
ETCS L2 FS	European Train Control System Level 2 Full Supervision
Journey Profile	A set of timetable, route and other operational data describing a journey to be made by an automatically operated train
Passing Point	A point along the route which, using ATO, is passed at a specifically defined time.
RBC	Radio Block Centre
RCS	Rail Control System (the SBB TMS product's scheduling system)
RU	Railway undertaking
Segment Profile	A set of infrastructure data required for conducting automated movements.
Shift2Rail	The EU's Railway Innovation Initiative
SS125	Functional system requirements for an interoperable "ATO over ETCS" system, restricted to GoA1 (C-DAS) and GoA2 (excl. GoA3 and GoA4).
SS126	ATO-OB / ATO-TS Interface (FFFIS)
SS130	ETCS-OB / ATO-OB Interface (FFFIS)
SS139	ATO-OB / Train Interface (FFFIS)
Stopping Point	A stopping point along the route at which ATO stops at a specifically defined time.
TCMS	Train Control and Management System, vehicle control technology
TMS	Traffic Management System (scheduling system; the SBB's RCS)
TSI	Technical Specification for Interoperability

1. Management summary

SBB's ATO2Basic pilot examined the standards which will be set out in the forthcoming TSI 2022 for ATO GoA2 in order to determine whether they are feasible and to ensure that they do not adversely affect Swiss railway operations; the pilot also examined whether ATO GoA2 can be controlled by a TMS, in this instance the SBB's RCS. Furthermore, a proof of concept was to be produced to determine whether the standards are already operationally compatible with the current ETCS Baseline 2.3.0.d. Phase 1 was completed in 2019 and is documented in Reference 4. This document describes the results of Phase 2, which was carried out in 2019 and 2020.

The objectives of ATO2Basic Phase 2 were fully achieved. ATO operation in GoA2 is possible with ETCS Baseline 2.3.0.d without any adverse effect on rail operations, including dynamic timetable specifications from the RCS. Extensive observations of the vehicle's driving ("ride") behaviour were undertaken.

- The outcome of these driving behaviour observations was that the ATO-OBU functional sample which was used – a sample without performance requirements – has the potential, even if it deviates a few seconds from the timetable, to stop precisely at a specified stopping position and that it therefore runs in an energy-optimised manner. The plausibility of the energy-saving potential (up to 42%) claimed by the industry was confirmed by separate measurements, which showed up to 37%. (See section 5.6)

- If required, ATO runs close to the defined system limits, such as acceleration behaviour and the conservative ETCS braking curves. The possibility of lowering the existing braking curve reserves for GoA2 train movements should be analysed as part of capacity planning. (See section 5.3)

- The ATO-OBU functional model complies 100% with the instructions given to the locomotive driver for the stopping position for long-distance services. The smartrail 4.0 requirements of +/- 1.5m are 97% met by the existing balises (which roughly correspond to the Shift2Rail recommendations). (See section 5.5)

- The functions implemented in the ATO OBU which we used illustrate the contribution they make to precise vehicle control, and thus to the optimisation of rail operations in terms of punctuality and node capacity. At the same time, they also reflect standard rail operations with functions for adhesion control, operational situations and door control options.

In phase 2, testing was carried out using a functional sample of an ATO-OBU supplied by Siemens. The functional sample was temporarily installed in a Stadler FLIRT vehicle. All the interfaces were implemented in accordance with the draft versions of TSI 2022; the connection to the train control system under ETCS BL 2.3.0.d was realised by fitting an adapter provided by the supplier to the relevant interface. On the infrastructure side, testing was carried out with the ATO-TS developed by smartrail 4.0, which was connected to the existing RCS. Apart from the ATO-TS, no changes or improvements were made to the infrastructure. In particular, the ETCS balises, which are important for localisation, were used in accordance with SBB's current ETCS project plans; there was no further optimisation by using additional balises.

1.1. Summary of test results

1.1.1. Achievement of the phase objectives

Objective		Remarks
ATO operation with all ATO-OBU interfaces in accordance with the draft TSI standard (as far as technically feasible)	✔	The live tests were carried out with an appropriately equipped ATO-OBU functional sample.
Rail operations with bidirectional interface to the ATO-TS and thus implementation of dynamic timetable specifications from the RCS	✔	Train movements were carried out with appropriate directives; implementation was demonstrated, and potential for improvement was identified
More far-reaching observations of driving behaviour with extended functionality compared to Phase 1 (see Sect. 3.2); determining potential	✔	These observations were carried out and are described in this document.
To observe and determine that ATO functionality does not adversely affect railway operations	✔	No adverse effects on railway operations were identified, but there is potential for optimisation.
PoC: ATO GoA2 with ETCS connection according to Subset 130 can already be implemented with ETCS Baseline 2.3.0d.	✔	ATO with GoA2 is already possible with Baseline 2.3.0d.

Table 1 Achievement of the phase objectives

➔ **The phase objectives were fully achieved**

1.1.2. New functions implemented in Phase 2

Function	Extent of fulfilment	Notes
Adhesion control	✔	Functionality implemented in the subsets; data input processes not defined
Speed restriction areas	✔	Functionality implemented
ATO inhibition zones	✔	Functionality implemented
Door control	✔	Functionality implemented
Skipping stops	✔	Functionality implemented
Powerless section	✔	Functionality implemented, improvement potential reported to Shift2Rail
Departure time	✔	Implementation only tested on the temporary DMI with no display
End of Movement Authority Offset	✔	Functionality implemented, improvement potential reported to Shift2Rail

Table 2 Degree of fulfilment of the Phase 2 functions

➔ **The newly implemented functions were successfully tested**

1.1.3. Further knowledge gained in Phase 2

Function	Extent of fulfilment	Notes
Punctuality	✔ Accurate to the second	Arrival time is kept, accurate to the second
Journey profile	✔	ATO runs very close to the ETCS braking curve
Stopping position accuracy	✔ +/- 1.5m	With balises positioned most effectively (as per Shift2Rail recommendations), the functional model already meets the requirements for regional services 100% and the smartrail 4.0 requirements (+/- 1.5m) 97%.
Energy-optimised running mode	✔	The plausibility of ATO's energy saving potential identified by industry as up to 42% was confirmed as 37% by separate measurements (example is taken from the referenced document 'DB Cargo Pilot Preparation Sion-Sierre')

Table 3 Further knowledge gained from Phase 2

➔ **Industry statements regarding ATO punctuality, journey profile, stopping position accuracy and energy-optimised running mode were verified.**

2. Introduction

This document summarises the knowledge gained from ATO2Basic Phase 2 which was carried out on the Lausanne-Villeneuve line to test the practical suitability of ATO GoA2. Testing was undertaken between November 2019 and June 2020; all the results were produced using draft versions of the relevant interfaces in accordance with the "Technical Specification for Interoperability" (TSI) and testing was carried out using a Baseline 2.3.0.d ETCS system. This section describes the general parameters for the test runs.

2.1. Objectives of Phase 2 of the ATO2Basic pilot

The stated objectives of Phase 2 of the ATO2Basic pilot were as follows:

- ATO operation with all ATO-OBU interfaces in accordance with the draft TSI standard (as far as technically feasible)
- Rail operations with bidirectional interface to the ATO-TS and thus implementation of dynamic timetable specifications from the RCS
- More far-reaching observations of driving behaviour with extended functionality compared to Phase 1
- To verify, through observation, that ATO functionality does not adversely affect railway operations
- Proof of Concept, that ATO GoA2 with ETCS connection according to Subset 130 can already be implemented with ETCS Baseline 2.3.0d.

2.2. Generic system architecture of ATO GoA2

The following figure illustrates the generic system architecture at GoA2 level; it also describes the most important function blocks including how ATO-OBU is embedded within the peripheral systems.

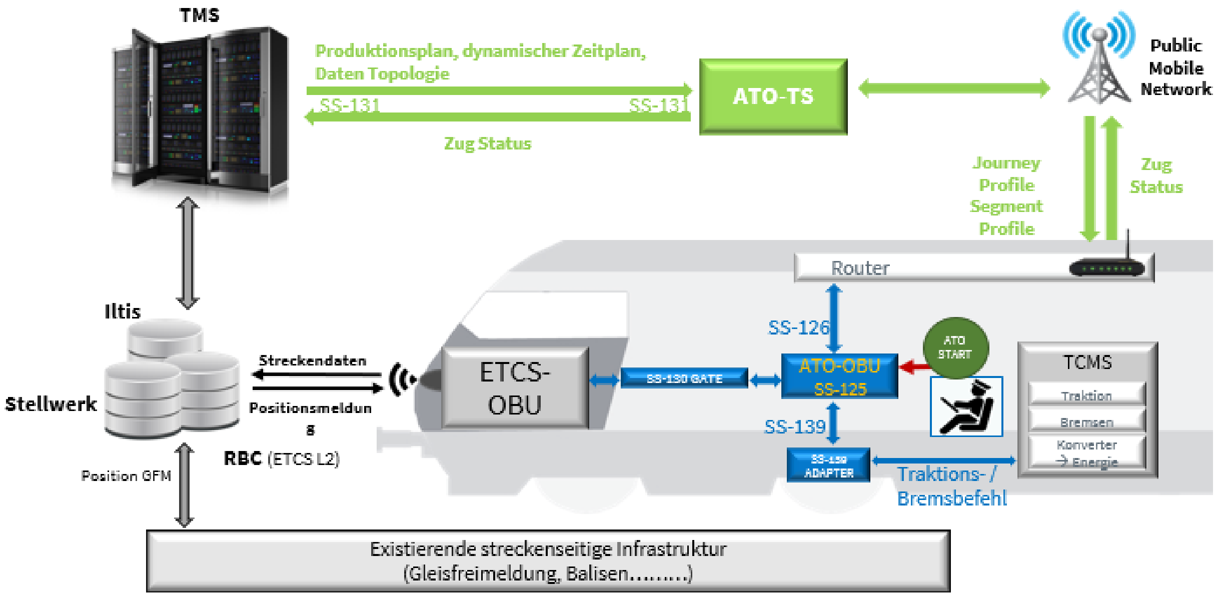

Figure 1 Generic system architecture

2.3. Test environment

The trials, or all the test cases, were held on the thirty-kilometre long route between Lausanne and Villeneuve, which has been upgraded to ETCS Level 2 FS. In addition to regional trains, intercity and freight trains also operate on this route. It is one of the few European ETCS L2 routes which handle regional services.

Figure 2 The test route

According to the SBB timetable, standard service journey times measured from the departure station are as follows:

Stn. no.	Stop/station	Arrival minute, outward journey	Departure minute, outward journey	Arrival minute, return journey	Departure minute, return journey
1	Lausanne		00	37	
2	Pully	03	03	33	33
3	Lutry	05	05	29	29
4	Villette VD	07	07	28	28
5	Cully	10	10	26	26
6	Epesses	11	11	23	23
7	Rivaz	14	14	20	20
8	St. Saphorin	16	16	19	19
9	Vevey	21	22	14	15
10	La Tour-de-Peilz	23	23	11	11
11	Burier	25	25	09	09
12	Clarens	27	27	08	08
13	Montreux	30	31	07	07
14	Territet	32	32	04	04
15	Veytaux-Chillon	34	34	02	02
16	Villeneuve	38	n/a	n/a	00

Table 4 Stations and departure times

Details of the infrastructure, of the vehicle including its equipment and of the current version of the standard are listed in the table below:

Title	Description
Test route	Lausanne-Villeneuve (30 km)
Stops/stations	13
Test vehicle	Stadler FLIRT (4-car S-Bahn multiple unit) 523 028
ATO-OBU	Functional model based on "S2R Pilot Line" supplied by Siemens in accordance with draft TSI 2022 standard
ETCS-OBU	Baseline 2.3.0.d supplied by Siemens with SS130 adapter
Infrastructure	ETCS L2 FS supplied by Thales (without any adaptations for ATO tests) Baseline 2.3.0.d
Draft standards	SS125 Version 0.1.0 / as at 04.05.2018 SS126 Version 0.0.16 / as at 07.05.2018 SS130 Version 0.1.0 / as at 04.05.2018 SS139 Version 0.0.9 / as at 01.02.2019

Table 5 Details of the test environment

2.4. Test organisation

A test organisation was established to carry out the planned trials and record the measurement results. A team of several people was involved in this process.

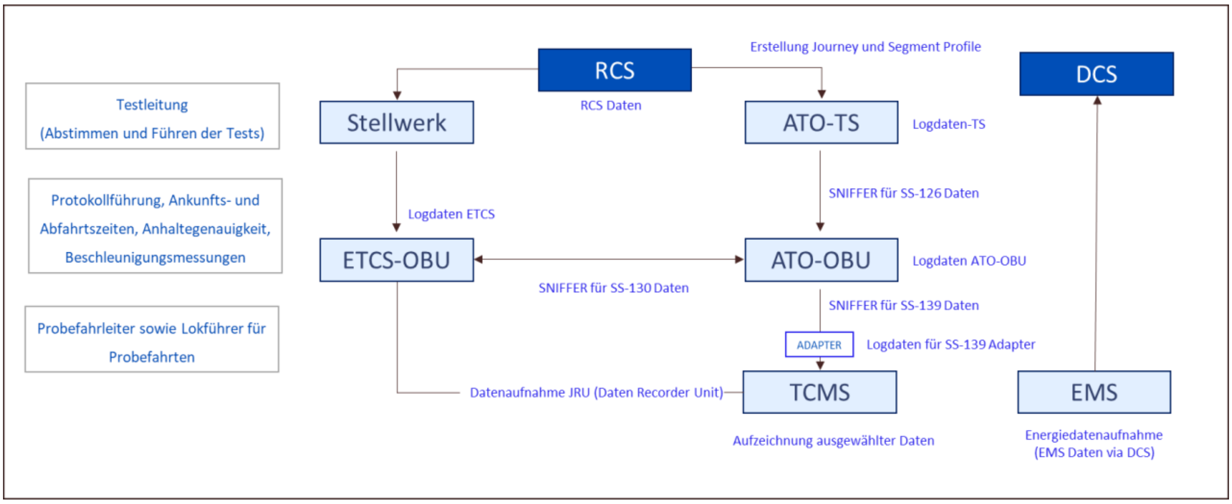

Figure 3 Test organisation and general overview of the system

This figure shows the various responsibilities in relation to the test system. In each case, the relevant data is shown at the corresponding interfaces. For example, the sniffer at the subsets is a device for recording the respective data transmitted; each recording device was supervised by a specified team member.

Responsibility for each task was clearly assigned to an individual team member. Certain tasks were carried out by non-permanent team members who were involved in the test runs on one or more test weekends. These are described as "Various" in the list of responsibilities.

Responsibility	Person responsible	Organisation	Remarks
Record keeping	Various	SR40, SBB-P	Test cases conducted, special occurrences (weather, etc.)
Noting arrival / departure times	Various	SR40, SBB-P	Using a GPS watch
ATO-OBU log data	Jens Nolte	SR40	Analysis only possible by the supplier (Siemens)
Creating the journey and segment profiles	Daniel Minder	SBB IT ATO-TS	Data from TMS to ATO-TS
ATO-TS log data	Daniel Minder	SBB IT ATO-TS	
SS-139 data	Michael Matthias	SBB-P	Sniffer between ATO-OBU and TCMS
SS-126 data	Michael Matthias	SBB-P	Sniffer between ATO-OBU and ATO-TS
SS-130 data	Michael Matthias	SBB-P	Sniffer between ATO-OBU and ETCS
SS139 adapter log data	Michael Matthias	SBB-P	The adapter's log files
JRU data	Franziska Wanner	SBB-P	TELOC® data recorder
Control system parameters	Franziska Wanner	SBB-P	TOP1131® Recording of selected control technology data
Energy data	Various	SBB-I-EN	EMS data via DCS
RCS data	Various	SBB IT, SR40	
Locomotive personnel for test runs (LfP)	Various	SBB-P	
Safety for door opening test cases	Various	SR40, SBB-P	
Test run manager (PFL)	Various	SBB-P	Contact with the traffic controller in the operations centre
Vehicle conversion	Michael Matthias Franziska Wanner	SBB-P	
Test director	Franziska Wanner	SBB-P	Coordination and conduct of the tests with all persons involved
ETCS log data	Franziska Wanner	SBB-P	(for part)
DDS	Franziska Wanner	SBB-P	Occurrence data control technology (for part)
Video recordings	Franziska Wanner	SBB-P	Using GoPro (for part)
Stopping position	Various	SBB-P, SR40	Distance measurements at stations
Energy data	Various	SBB-I-EN	
Data evaluation, analysis	Xiaolu Rao	SR40	

Table 6 Test team roles

2.5. Raw data recorded

The figure below provides an overview of the raw data recorded. It shows the location where the raw data that was subsequently used for the analyses in this report was collected.

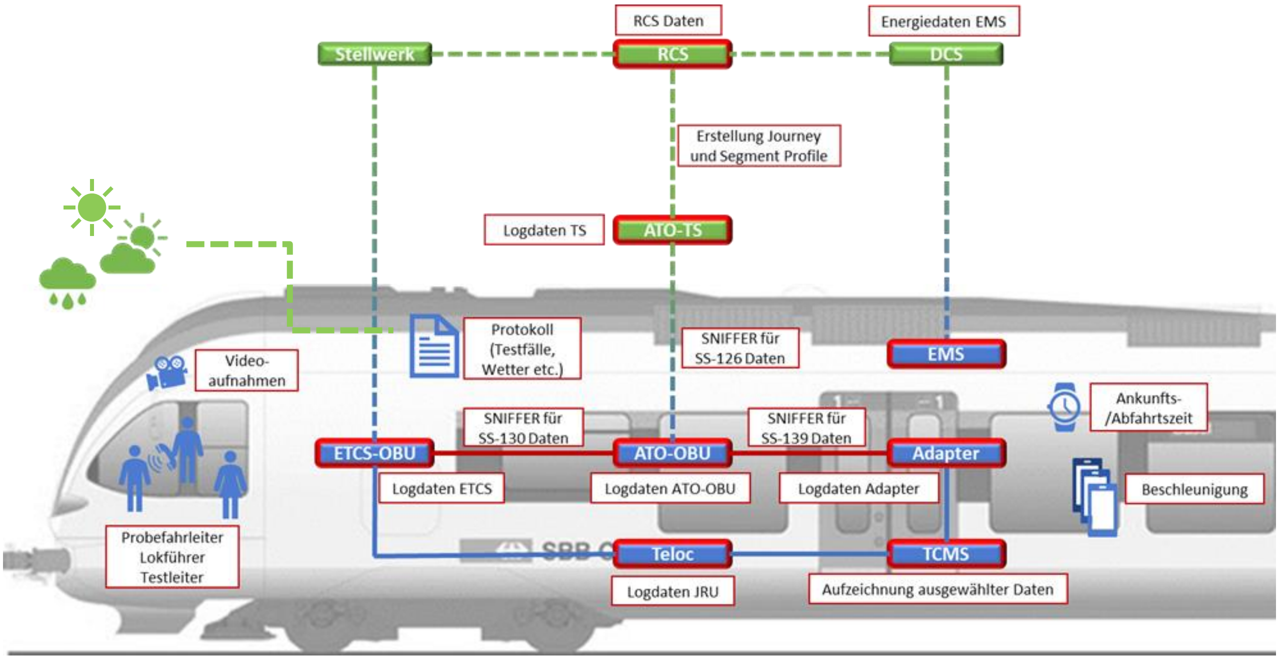

Figure 4 Data collected

Some data was recorded manually. Similarly, the log data of some systems was stored. Activity at the interfaces was continuously logged by means of a sniffer that was looped into the Ethernet connection. The video recordings were made using a camera on the driver's console. They were made in case it was necessary to reproduce occurrences on the route; they have since been deleted.

2.6. Test cases

In order to be able to evaluate the applicability, completeness and practicability of the draft ATO GoA2 TSI standards, a total of 105 different test cases were carried out with varying frequency. The figure below shows the test distribution by category.

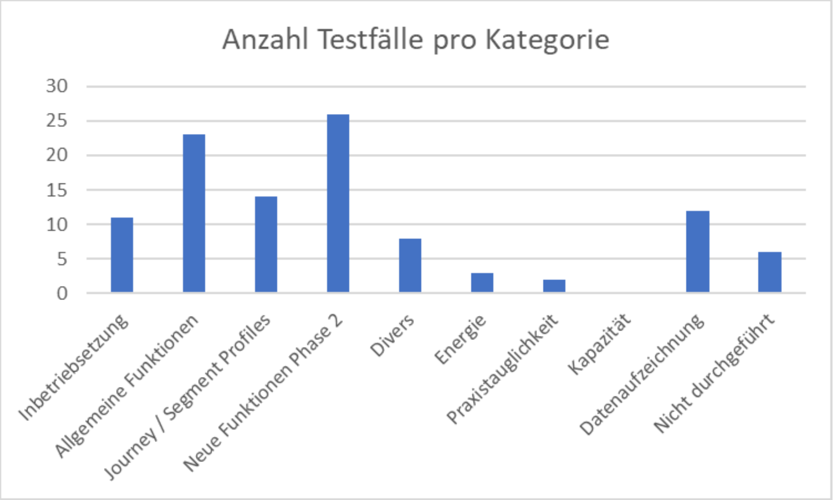

Figure 5 Number of test cases per category

The "New Phase 2 Functions" category refers to the additional ATO-OBU functionality in the SS125/126; this additional functionality compared with the Phase 1 ATO-OBU was implemented by the supplier (Siemens).

Note about the "Capacity" category: due to the reduced budget for ATO2Basic, the relevant test cases could not be carried out during the available test weekends.

Details of the test cases are set out in Reference Document 3 "ATO2Basic Phase 2 test cases V.1".

3. Setting up using the supplier's (Siemens) ATO OBU functional sample

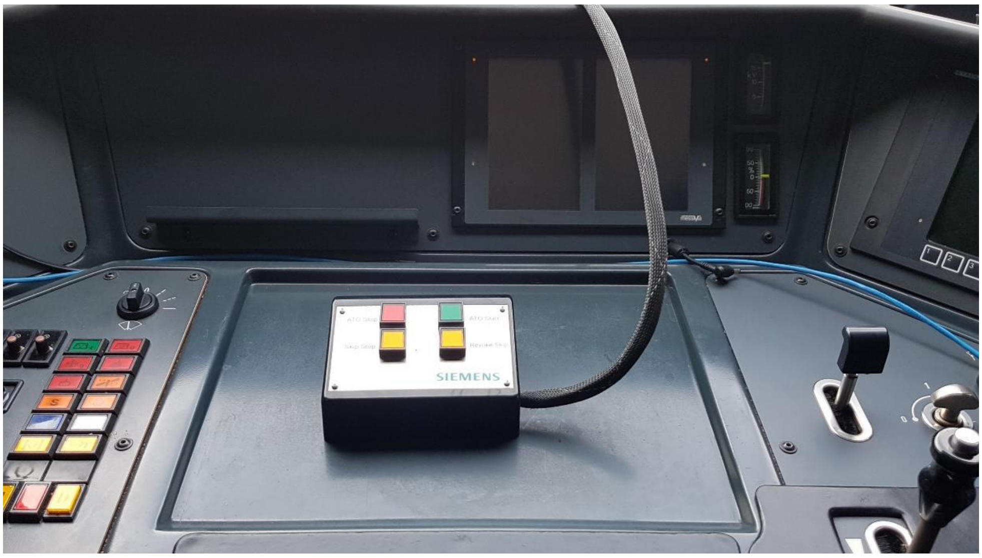

Figure 6 "Provisional DMI" functional model

The ATO OBU does not have a DMI conforming to the draft standard, i.e. a DMI which is realised via the ETCS display. It is operated via a simple DMI without a screen and consists of the following controls:

- ATO Start: Switch on automatic driving mode
- ATO Stop: Switch off automatic driving mode
- Skip Stop: Skip station stops (see section 3.2.5)
- Revoke Skip: Cancel skipping station stops (see section 3.2.5)

Note: The provisional DMI has the partially optional control elements provided for in Subset 125. Because ETCS Baseline 3.7 was not available, the ETCS screen's display functions were not implemented on the vehicle. For this reason, neither the user interface nor its ease of use could be assessed in Phase 2 of the project. This is envisaged for, or will be possible from, ATO2Basic Phase 3.

3.1. Basic functionalities

First, in order to verify its operational suitability and the various functions in the draft ATO standards, the following basic functions were tested:

- Connection between ATO OBU and ATO TS for transmitting the journey and segment profiles (via the public mobile network)
- ATO Start / Stop
- Deactivating ATO using the drive/brake lever and driver brake valve
- The responsiveness of the safety device (ETCS)
- ETCS:
  - ETCS level boundaries (L2FS to L STM (ZUB) / L STM (ZUB) to L2FS)
  - Stop at End of Movement Authority
- Detecting data link interruptions (ATO-OBU to ETCS/TCMS)
- Behaviour when approaching Passing Points / Stopping Points
  - Passing through / stopping at the scheduled time
  - Updates: shorten/extend scheduled timings (production specification updates)
- Correct segment profiles and new routes via segment profile update
- ATO-TS to RCS link (for the test runs; SR40 TMS in future)

3.2. Functionalities implemented and verification thereof

The following functionalities were implemented and at least functionally tested:

- Adhesion control
- Speed restriction areas
- ATO inhibition zones
- Door control
- Skipping stops
- Neutral section
- Departure time
- End of Movement Authority Offset

The individual functions are described in detail in the sections below.

3.2.1. Adhesion control

The ATO-OBU is equipped with adhesion control in accordance with the draft SS125 standard. This functionality prevents the wheels from skidding or spinning when adhesion between wheel and rail is poor, for example on wet or icy rails.

The adhesion value can be transmitted in 10% steps from the ATO-TS (per segment profile) to the ATO-OBU via the SS126. The ATO-OBU adjusts its driving mode by appropriately reducing either its maximum traction demand or its braking demand.

If adhesion values are sent from the TCMS to the ATO-OBU via the SS139, the ATO-OBU forwards them onto the ATO-TS in a status message. However, the values from the TCMS were not used for control purposes in the ATO-OBU functional model we used.

In practical implementation terms, the adhesion values are superposed by the required tractive or braking force. It was noticeable that at adhesion values of <100%, the tractive or braking force is lower and the vehicle's driving behaviour changes accordingly.

When adhesion is good, this is only evident by the reduction in the demand for tractive force. When adhesion is poor, the wheel slide protection engages, from a subjective perspective, noticeably less frequently (compared with runs made without using adhesion control).

The adhesion control used in the functional sample was in accordance with the version of the standards shown in section 2.3. In the meantime, adhesion control has been subject to further development by the relevant committees. Consequently, adhesion control needs to be examined and tested in detail once again during the next scheduled ATO2Basic phases (3, 4).

3.2.2. Speed restriction areas

A maximum speed, which differs from the general line speed, can be defined in certain areas for each segment profile. This functionality was implemented and successfully tested.

3.2.3. ATO inhibition zone

An ATO inhibition zone (train operation using ATO prohibited) can be established in certain areas for each segment profile. The locomotive driver will therefore need to take control of the vehicle. If the vehicle enters an ATO inhibition zone, the ATO-OBU changes to "Disengaging" mode ("will be deactivated"). If the driver does not take control within 5s, the vehicle will brake with maximum braking force. The ATO inhibition zones were successfully tested.
Note: Only the functionality as described in Subset 125/126 was implemented. Displaying the ATO inhibition zone on the DMI, as envisaged in SS125, was not realised in this functional model. (See also Sect.3)

3.2.4. Door control

When the train is stationary, the ATO-OBU can activate the door release function on the side specified by the journey profile. The ATO-OBU can, moreover, perform a complete cycle (release-open-close-lock). The complete functionality was realised and successfully tested.
Note: Additional staff were specifically employed to ensure safety during testing.

3.2.5. Skipping stops

The "Skip Stopping Point" function can be activated both by the locomotive driver and by the journey profile. The locomotive driver can cancel "Skip Stopping Point" with the "Revoke Skip" button. This is regardless of whether the instruction was initiated manually or by the journey profile. This function was carried out under every set of circumstances in the relevant test cases.

3.2.6. Powerless section

Since there is no powerless section on the Lausanne-Villeneuve line, a powerless section was simulated in the segment profile. As expected, the ATO-OBU did not request any tractive force when passing through this fictitious neutral section. It was not possible to verify how a powerless section is included when calculating the journey profile, as the control algorithm is the intellectual property of the supplier.

3.2.7. Departure time

If appropriately defined in the journey profile, the display on the DMI can inform the locomotive driver that it is not yet time for the train to depart. On the functional sample which was used, this is done by an illuminated display on the relevant push button. According to the future TSI, the information will be displayed in the ETCS DMI under Baseline 3; it can be supplemented by push buttons / switches. Since a currently approved ETCS BL 2.3.0d was used for the tests, the information (departure time) could not be tested on the DMI. However, indicating the departure time by means of an illuminated display on the corresponding push button was tested successfully.

3.2.8. End of Movement Authority Offset

Before an End of Movement Authority (EoA), the train comes to a halt with an offset that can be defined in the segment profile. This was verified using a range of different values. The vehicle stopped at the specified distance from the ETCS stop signal. It was found that it would help the locomotive driver if the EoA offset were displayed on the DMI. The standard does not currently envisage this, but we included this recommendation in our feedback to Shift2Rail.

3.2.9. Summary of the findings of the review

Function	**Extent of fulfilment**	**Notes**
Adhesion control	✔	Functionality implemented in the subsets; data input processes not defined
Speed restriction areas	✔	Functionality implemented
ATO inhibition zone	✔	Functionality implemented
Door control	✔	Functionality implemented
Skipping stops	✔	Functionality implemented
Neutral section	✔	Functionality implemented, improvement potential reported to Shift2Rail
Departure time	✔	Implementation only tested on provisional DMI
End of Movement Authority Offset	✔	Functionality implemented, improvement potential reported to Shift2Rail

Table 7 Summary of degree of fulfilment of new functions

The basic functionalities were implemented in the ATO-OBU in accordance with the draft standards and also tested accordingly. The implementation of the specifications was confirmed.

4. Observations from the trials carried out

The following points were observed during the test runs on the Lausanne-Villeneuve line between September 2019 and June 2020:

4.1. Basic driving behaviour

4.1.1. Arrival time

Summary

- Irrespective of the departure time, "ATO start by the locomotive driver", the ATO OBU controlled the train based on the target arrival time and achieved a degree of punctuality which lay within the range of a few seconds.
- For complete punctuality, it was equally important that the start of the ATO journey was initiated on time.

Where fixed departure and arrival times are specified in the journey profile, the ATO-OBU calculates the journey profile in such a way that the vehicle arrives on time (accurate to the second). Punctual arrival can only be achieved if there are no restrictions on the route, such as signal stops or unplanned speed limits. The ATO-OBU was optimised for punctuality by the supplier as it was being prepared for use. All the relevant test cases resulted in arrival times, as defined in the journey profile, within the range of a few seconds.
The two graphs below provide examples of the recorded punctuality data.

<u>Example 1</u>

Figure 7 ATO run between Vevey (VV) and St. Saphorin (STSA) shows that the vehicle has reached the defined stop position in St. Saphorin one second too early, although the ATO start button was pressed 14 seconds too late in Vevey.

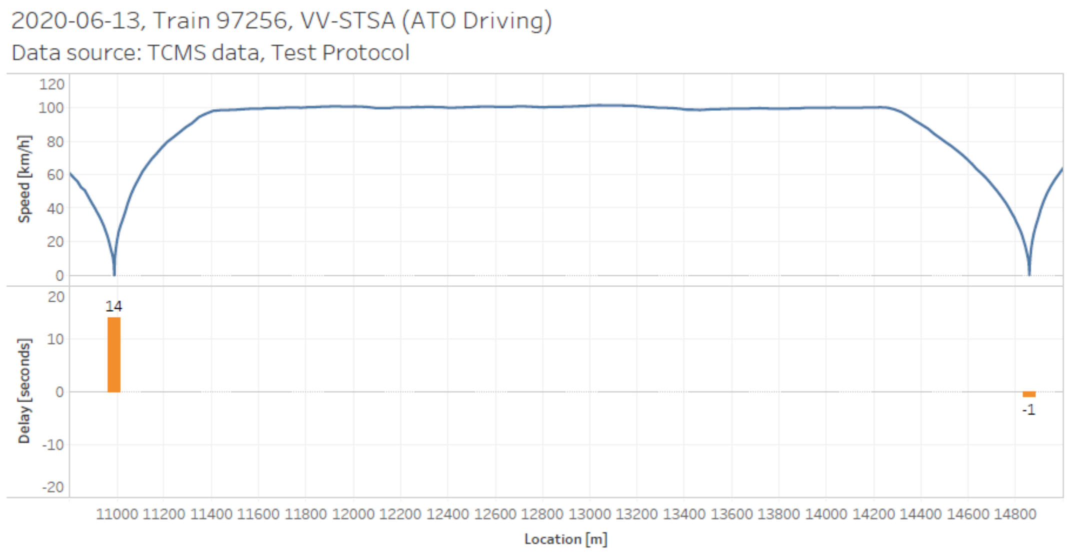

Figure 7 ATO run between Vevey (VV) and St. Saphorin (STSA)

Example 2

Figure 8 (Montreux-Territet section) specifically shows that the ATO OBU always works towards achieving a punctual (accurate to the second) arrival time. If "ATO start" is initiated punctually, the vehicle will arrive at the specified time, accurate to the very second; the journey is also optimum as regards its economic aspects (optimum energy requirement).

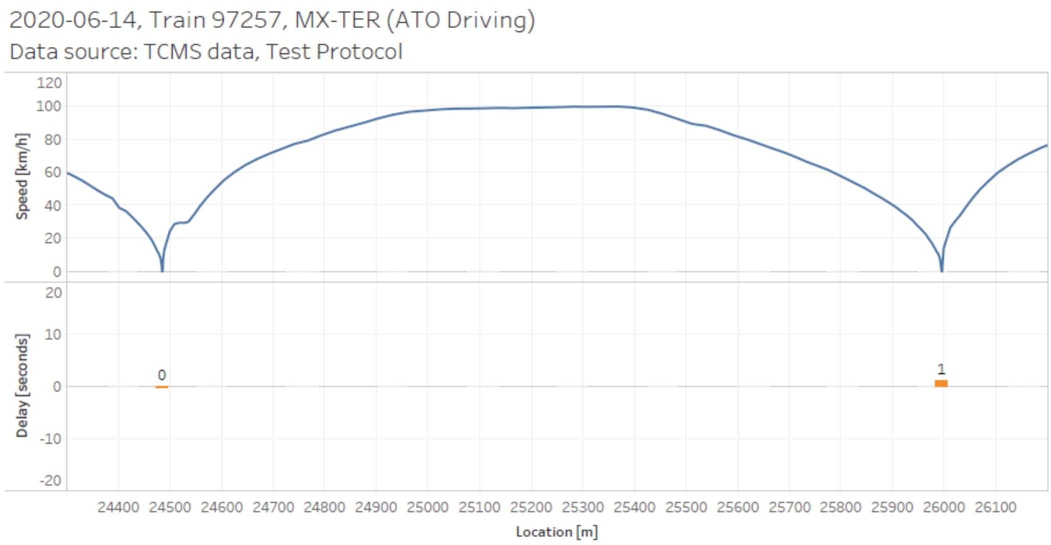

Figure 8 ATO run between Montreux (MX) and Territet (TER)

4.1.2. Stopping position

No absolute stopping positions were available during the test runs. These were only worked out during follow-up action.

To determine stopping accuracy, the relative variation in the stopping positions was measured. This was achieved by marking the position of the leading edge of the first door's retractable bridge plate during the first ATO run. Deviations from the marked position were measured during the subsequent runs.

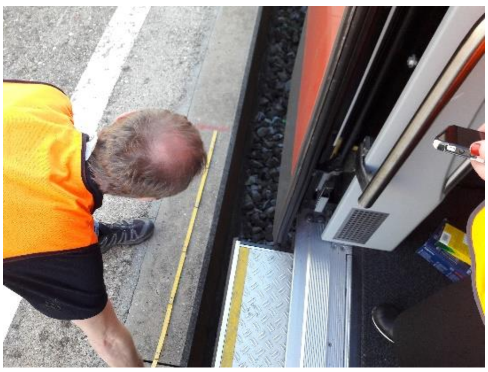

Figure 9 Measuring the differences in the stopping positions

4.1.3. Stopping procedures

Statistics illustrating the variations between 215 individual measurements were drawn up based on the variations between the stopping positions on the Lausanne-Villeneuve route. (Relative stopping accuracy)

The accuracy depends on the infrastructure, especially the positioning of the ETCS balises. The ATO-OBU uses the ETCS balises to determine the train's position; it calculates its current position based on the distance travelled from the last balise. For technical reasons, the accuracy of the odometry decreases as the distance from the last balise passed increases; the position identified becomes less accurate. Model calculations by Shift2Rail have shown that to achieve maximum accuracy for the ATO stopping position, a balise needs to be positioned about 70m before that stopping position.

General measurement conditions:

- Only the existing ETCS infrastructure to be used
- Balises not to be optimised or positioned for ATO operation; existing SBB ETCS project planning guidelines
- Distance between balises and stopping location to be up to 800m

The relative stopping positions this produces are illustrated below:

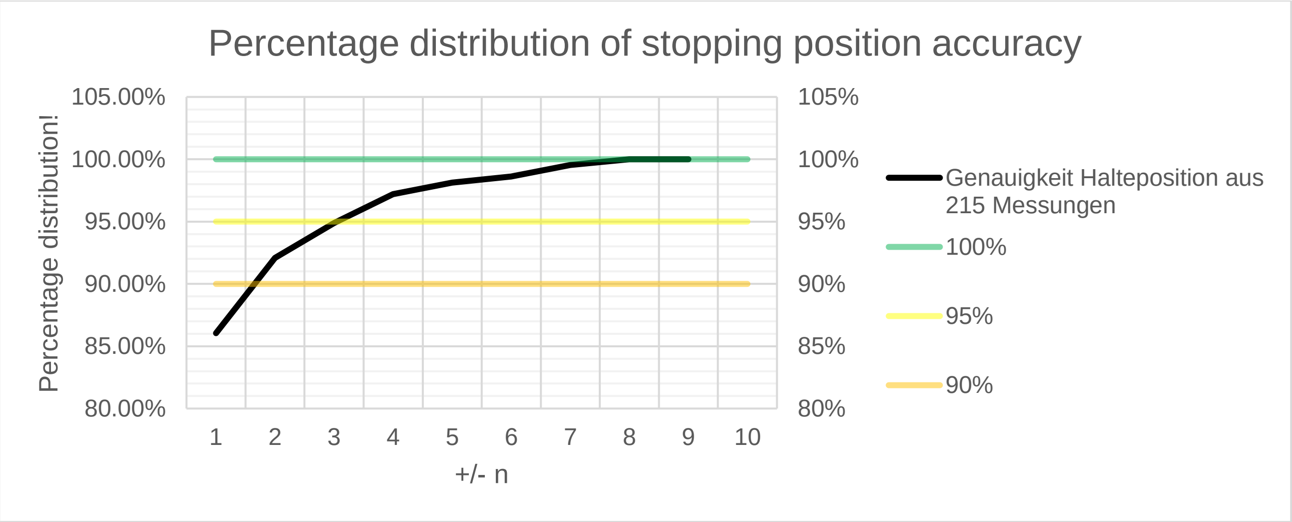

Figure 10 Stopping position (215 measurements)

The values along the graph's X-axis represent the tolerance window for the accuracy of the stopping positions; the Y-axis shows the percentage of measurements that are within this tolerance window.
As the size of the window increases (i.e. as the accuracy of the stopping positions decreases) a higher percentage of the measurements is within the tolerance window.

4.1.3.1. Analysis of compliance with the specifications

Summary

- **100%** of the stopping positions measured on existing ETCS lines already meet the specified +/- 10m laid down for locomotive drivers on long-distance services.
- **100%** meet the specified +/- 5m for regional services assuming optimum positioning of the balises (97% across all measurements irrespective of the distance between balises)
- **97%** meet the smartrail 4.0 specification (< +/-1.5m) assuming optimal positioning of the balises (85% across all measurements irrespective of the distance between balises)

Within SBB, there are different specifications for stopping position accuracy:

- Smartrail 4.0 has defined a requirement for stopping position accuracy of +/- 1.5m.
- Training documents for locomotive personnel show a recommended stopping position accuracy of +/- 5m for regional services, or +/-10m for long-distance services

The 215 measurements of stopping position accuracy illustrated in Figure 10 were compared with the specifications stated above. This showed that the +/- 10m specification for long-distance services was met 100%.

If the tolerance window is reduced to +/- 5m (specification for regional services), 97% of the measurements are within this window, i.e. only 3% of the measurements did not comply with the specification for regional services.

A further reduction of the tolerance window to the smartrail 4.0 specification of +/- 1.5m shows that 85% of the measurements are included in this window. Ignoring the 3%, i.e. the value which only relates to the specification for long-distance services, 12% are outside the SR40 specification, but within the specification for regional services.

The figure below illustrates this distribution diagrammatically.

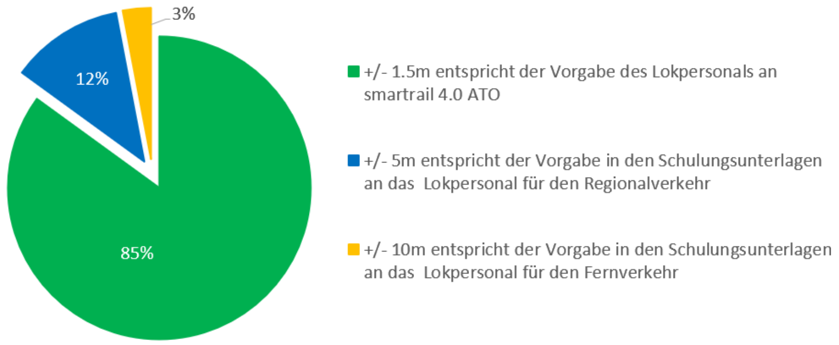

Figure 11 Percentage compliance with the specifications

This analysis contains all the measurements made, regardless of the distance between the last balise passed and the stopping position.

In order to estimate the potential of the draft standards, a further analysis only used the 61 measurements in which the last balise passed before the stop was located at the optimal distance of about 70m before the stopping position; i.e. the distance recommended by Shift2Rail.

This produces the following distribution:

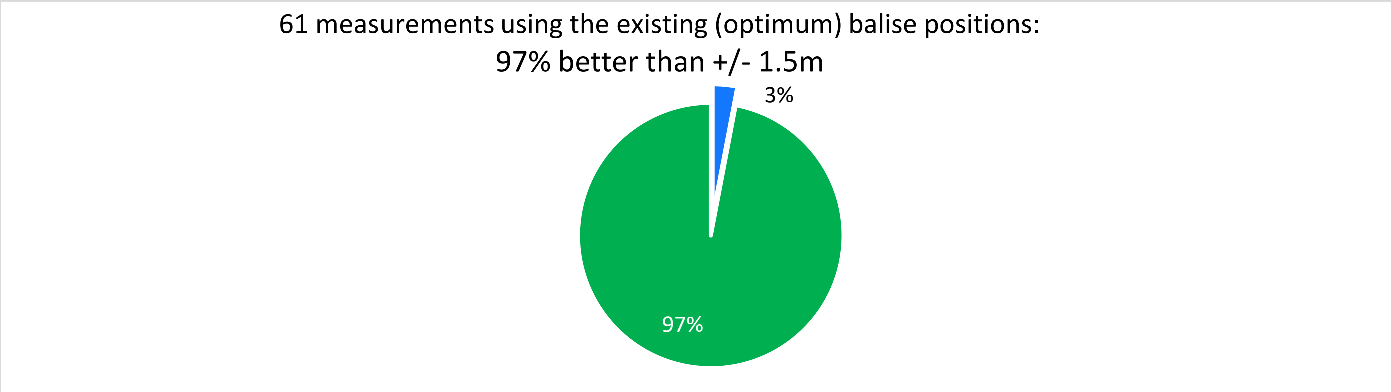

Figure 12 Stopping position with ATO-OBU functional model and optimum balise positioning

The specifications locomotive drivers on regional services were complied with 100%.
In 97% of all cases, the smartrail 4.0 specifications were adhered to; 3% of the measurements did not lie within this specification but were within the specifications for regional services.

4.1.3.2. Analysis of the stopping position's dependence on distance from the balise

Summary

- If the distance between balise and stopping position is greater than the recommended distance of approx. 70m, the accuracy of the stopping position decreases.

After determining the absolute stopping positions, an analysis was produced which shows that stopping position accuracy depends on the position's distance from the last ETCS balise passed. It can be seen that the accuracy decreases as the distance between the balises and the stopping position increases.

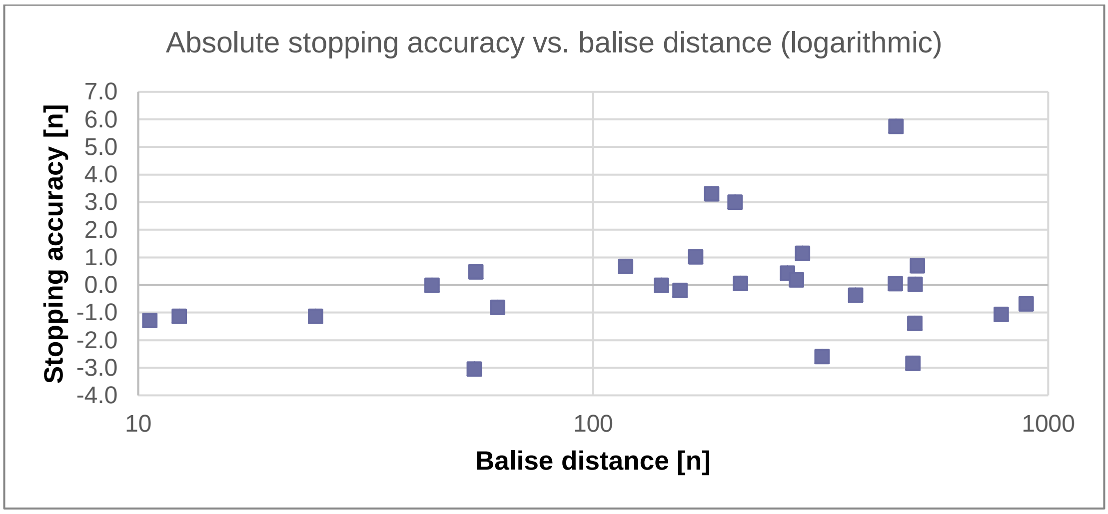

Figure 13 Stop position accuracy depending on distance between balise and stop position

4.1.3.3. Next steps

In Phase 3, once the definitive standards have been implemented, a fresh analysis of stopping accuracy will have to be carried out. Thereafter, the remaining "outliers" must be analysed in detail to determine why they failed to conform to the specifications.
The interdependence between odometry, balise positions and the database used for the segment profiles must be ascertained in detail both as regards the OBU and the infrastructure.

4.2. Further consideration of driving behaviour / additional parameters

4.2.1. Reducing delays

Summary

- If a departure is delayed, the ATO-OBU will endeavour to keep to the arrival time as scheduled according to the journey profile.
- Delays will thus either be made up for in the most effective way while adhering to the system limits (acceleration, driving close to the braking curve) or they will be reduced to the minimum achievable.

Example 1

Train number 97180 on 23.02.2019
Scheduled running time from Veytaux-Chillon to Pully: **30 min and 12s (1812s)**
Number of station stops to Pully: **13**
Delay made up: **194s**

Due to the operational situation the departure from Villeneuve and the onward journey from Veytaux-Chillon were delayed. The ATO-OBU endeavoured to keep to the arrival times as scheduled in the journey profile

The graph below shows that on this test the delay of 360 seconds **was reduced** by **194 seconds** over the entire route. Thus, the delay on arrival at the destination station was only 166 seconds. The passenger changeover times were simulated by measuring the stopping position and were adhered to in accordance with the specifications (minimum stopping time of 15 seconds according to Document "P20000826: Operating Regulations" SBB-P, 6.3, Point 1).

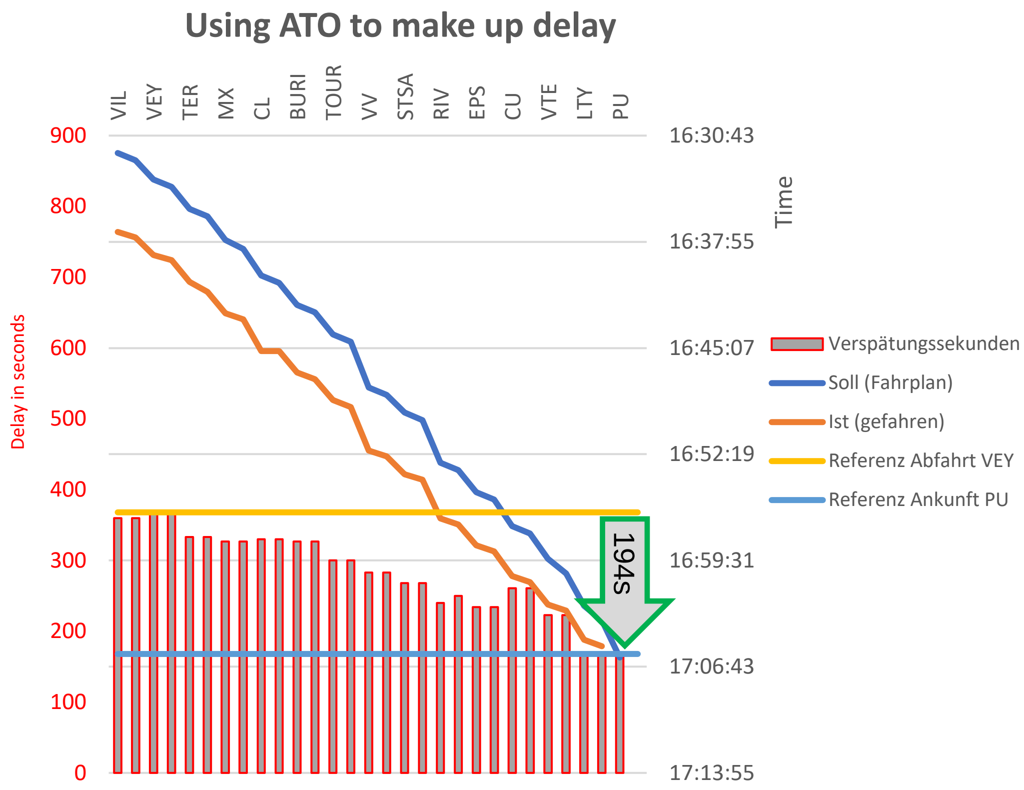

Figure 14 Reducing delay, Example 1

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After a delayed departure from Veytaux-Chillon, **194 seconds were made up for** by the end of journey in Pully (1 station stop before Lausanne). With a total of 13 stopping points (stations) on the route, it is clear that on such routes the stopping time or the process of passengers getting on and off the train plays a significant role (the minimum stopping time is 15 seconds) and therefore the precise stopping position is also important for optimal passenger changeover.

An experienced locomotive driver could / can also optimise the timings. However, it is important to note that constantly driving at the limits for a lengthy time imposes additional stress on the locomotive driver. In contrast, under ATO operation, it is perfectly possible for the train to be driven at the limits for long periods of time leaving the train driver to concentrate fully on safety issues.

Example 2

Train number 97255 on 14.06.2019

Scheduled journey time from Pully to Villeneuve: **30 min and 12 s. (1812 s.)**

Number of station stops from Pully: **14**

Delay made up: **194s** within the scheduled time of 1524s. (Pully to Clarens).

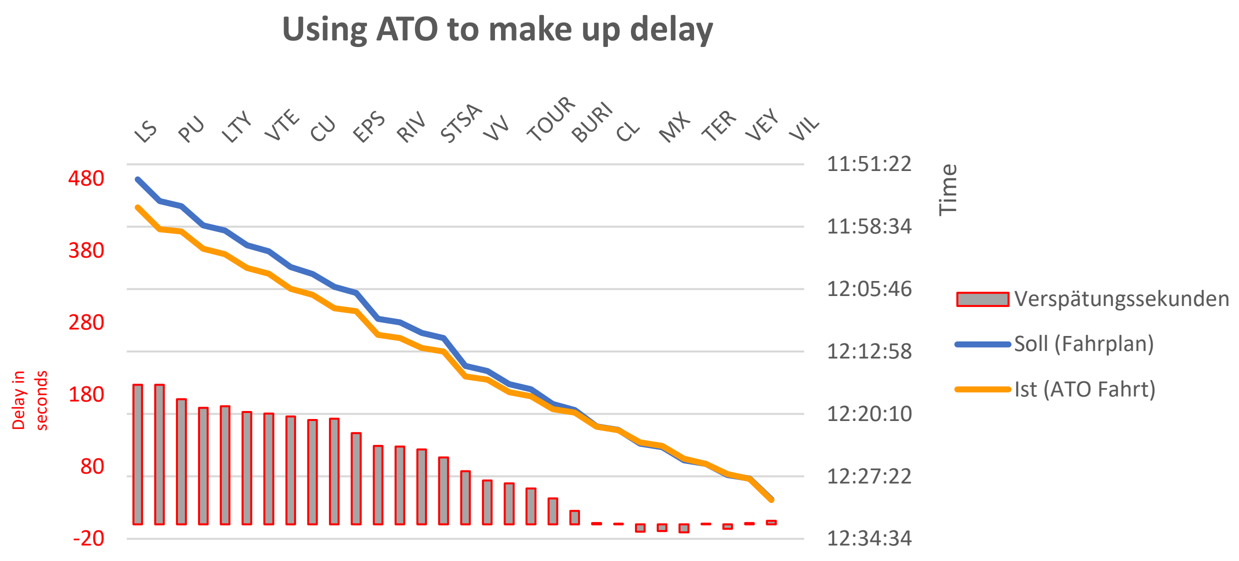

Figure 15 Reducing delay, Example 2

This example, too, shows that the number of seconds delay can be reduced or that the delay can be fully compensated for. The departure from Pully was delayed by 194s. (It is coincidental that this is the same number of seconds as the delay that was made up for in Example 1). The train arrived on schedule in Clarens ten stops later. Punctuality from Clarens to Villeneuve varied within a few seconds of the scheduled times.

Summary based on these examples

By consistently pushing the journey profile to the system limits, such as braking curves and maximum acceleration values, ATO makes up for delays within the bounds of what is possible and, at the same time, drives up to precise stopping positions.

Achieving the same under manual control would demand an extremely high level of concentration over the entire route.

The identical value shown in both examples for the reduction in delay is purely coincidental.

4.2.2. Driving close to the braking curve

Summary

- If delayed, ATO runs very close to the braking curve as far as the end of Movement Authority.

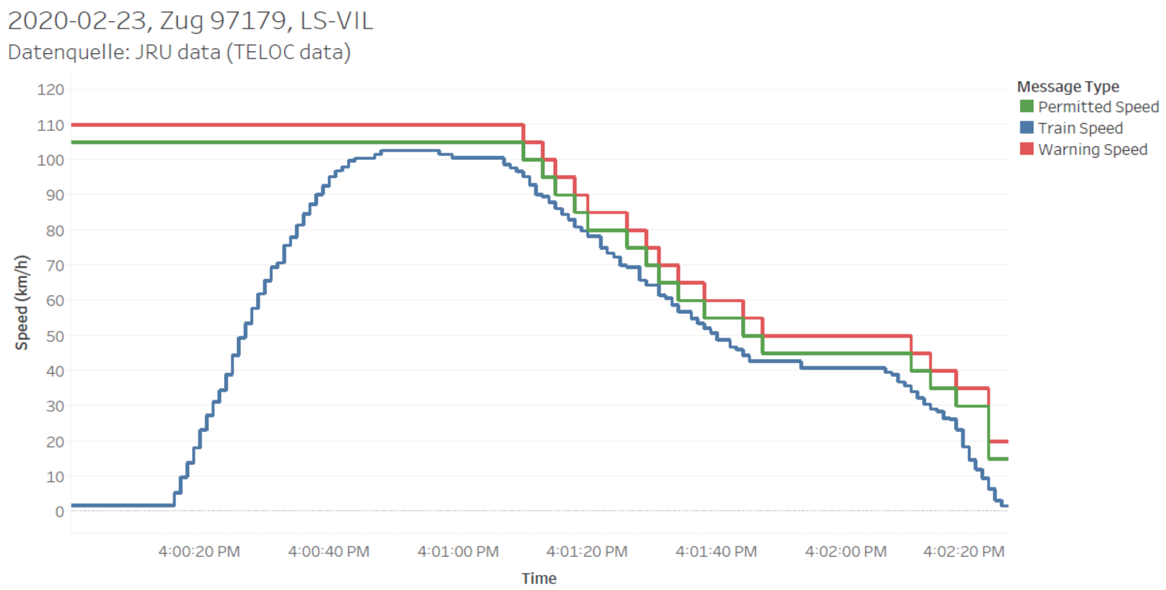

Figure 16 Driving close to the braking curve

Figure 16 clearly shows the ATO driving behaviour as regards driving right up to the braking curve: The journey took place very close to the ETCS "permitted speed" but with a reserve below the "warning speed" curve.

4.2.3. Energy consumption

Summary

- To obtain a representative survey of the energy-saving potential, further extensive and reproducible comparative runs with clear instructions for the locomotive driver, with different drivers and under different weather conditions, would need to be carried out.
- A comparison run clearly showed the very different driving styles adopted by the locomotive driver and ATO. In one case, energy consumption during ATO operation was approx. **25%** less than energy consumption during manual operation**.**

Non-representative initial measurements of energy consumption were carried out during the test runs.
Those test cases which were evaluated were individual comparison runs. Not all runs were evaluated, as it would have been too costly and time-consuming to follow up all test cases with manual comparison runs. Verifying energy consumption was not the main focus of Phase 2.

After initial observation of the general differences in driving behaviour over the route (to compare from what point and in what manner the brakes were applied, or how the train was driven when coasting), a specific comparison of energy consumption was made under as similar conditions and time constraints as possible (in accordance with the stated priority of "punctuality before economic efficiency").

Notes:

- According to the manufacturer, the OBU functional model used for Phase 2 had been optimised for punctual arrival. This meant that ATO always used the entire time available until the scheduled stop and that the energy-optimised driving mode was based on this parameter.
- An energy-saving driving style was not the foremost consideration for the test cases with the Phase 2 functional model.
- A continuous Movement Authority applied up to and beyond the stopping point

Figure 17 provides a direct comparison between a manually driven and an ATO driven section between Villette and Cully. The instruction to the locomotive driver for the manually driven run was "to keep to the specified travel time as precisely as possible". The locomotive driver carried out this instruction splendidly, with a time difference of < 1s. Both runs took place in dry weather and therefore good adhesion.

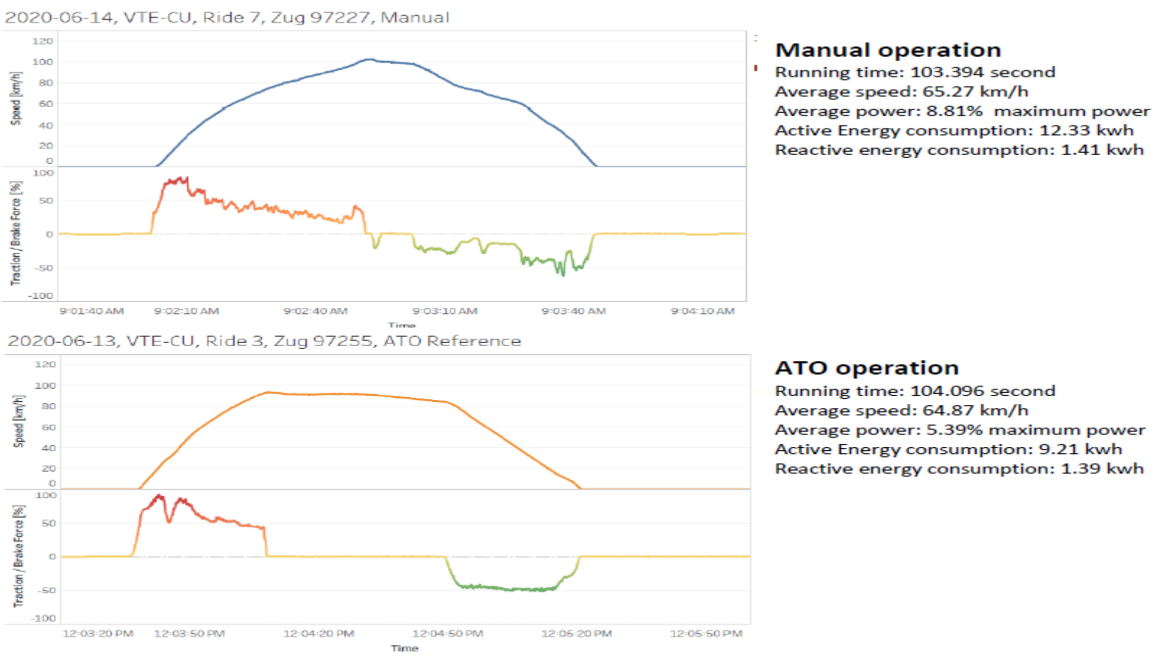

Figure 17 Comparison of manual vs ATO energy consumption

The comparison shows speed and traction/braking demand (only illustrated electrically, incl. recuperation; energy calculations incl. pneumatic braking) measured over time on the section of track between Villette (VTE) and Cully (CU).

In this example, the time difference between the manual and ATO runs was approx. 0.7 seconds, meaning that any difference in running time can be ignored as regards energy consumption.
When comparing the driving behaviour, it is interesting to note that, during the manual run, acceleration or deceleration (recuperation) occurred over almost the entire length of the route, i.e. the train was subject to continuous control, whereas ATO first accelerated more powerfully, then coasted along a section and afterwards braked more sharply. In this example, the energy consumption with ATO was approx. **25%** less than the manual operation energy consumption.
To obtain a representative survey of the energy-saving potential measured, further test runs must include the highest possible number of comparison runs with different locomotive drivers and under different weather conditions.

4.2.4. Potential for smoothing load peaks:

From an energy supply point of view, it would be desirable to significantly reduce the energy consumption of an ATO operated train for a short period in order to smooth out load peaks. Therefore, the ATO team was asked whether they could examine what the response times would be for such a request. In order to evaluate this, the following test case was carried out on several sections of track:

- During the journey, an updated journey profile, including a significantly later arrival time at the next stopping point, was sent to the ATO OBU
- This caused the OBU to significantly reduce the train's speed (with a corresponding reduction in its immediate energy consumption).

The time between the ATO TS (TMS) sending the journey profile and the reaction by the ATO-OBU was measured as between 1 and 3 seconds. However, it was not possible to investigate whether this latency period is representative for the transmission chain (internet and mobile network).

There are currently no specific requirements for the "smooth out the load peak" application scenario. Further investigation is needed to determine whether this measure, as tested, represents a suitable solution for smoothing out load peaks, taking into account latency periods and already foreseeable changes such as the changeover to the future railway radio network FRMCS. Any such investigation would need to be backed up by measurements and then analysed and defined in collaboration with the respective technical department.

4.2.5. Adhesion

Summary

- No relevant differences in ATO driving behaviour were found between driving on wet and dry rails.

The "Adhesion Control" functionality was tested during the setting-up phase (see section 3.2.1). If a poor adhesion value is transmitted to the ATO OBU (via a segment profile), the tractive or braking force will be reduced accordingly.

No poor adhesion conditions occurred during the test weekend of 22/23 February; there was rain, and therefore poor adhesion, on a few runs during the test weekend of 13-14 June.

As regards stopping accuracy (positioning and timing), the measurements showed no statistically significant differences between dry and wet rails. However, since no adhesion values were transmitted via the ATO-TS without having been specially processed manually, wheel slide protection engaged audibly more frequently when accelerating on wet rails.

Figure **18** below compares stopping on wet rails (left) with stopping on dry rails (right). Also, when considering the driving profile (the closeness of the braking curve shown in blue (i.e. speed) to the permitted speed shown in green) no significant differences can be found.

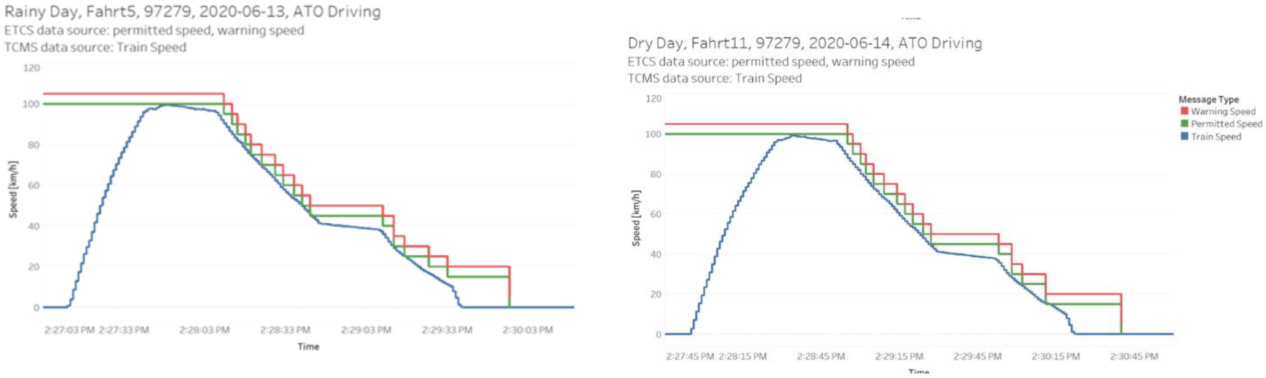

Figure 18 Comparison of braking behaviour with good and poor adhesion

4.2.6. Driving behaviour on powerless sections

As there is no powerless section on the line between Lausanne and Villeneuve, this functionality could only be tested as part of ATO2Basic Phase 2 by a simulated powerless section. As the train entered the powerless section (as defined by the segment profile) the ATO OBU no longer requested tractive force.

4.2.7. Control by RCS / journey profile updates / control loops

Summary

- The timing of the journey profile updates during the journey influences the behaviour of the external and internal control loops (see Figure 19 below), and this has an impact on punctuality, energy consumption and passenger comfort. It was noticed that the journey profile updates tended to mount up. In order to achieve an acceptable degree of operational stability when ATO is introduced, it is essential that further analytical investigations and reviews are undertaken as soon as possible, before the specification is embedded in the TSI.

- The extent to which this depends on the vehicle type, with its system-specific characteristics, and on any other conditions (e.g. maximum acceleration, weight, ...) needs to be examined in detail.
- The optimum number of timing points between two stopping points should be examined.
- Coordinating the relevant requirements in this area is necessary so as to harmonise the two control loops between operational processes & requirements, TMS development and ATO.

4.2.7.1. The control loops – a general overview

An ATO-OBU is not a stand-alone onboard system, but rather an integration of trackside systems and onboard systems. The way in which a vehicle equipped with ATO is controlled can be represented within the system architecture by two closed control loops, as described below.

The internal control loop is installed on the vehicle and is controlled by the ATO-OBU. It controls the vehicle's driving behaviour between defined points on the line and in accordance with the instructions transmitted by the ATO-TS. These instructions are implemented either by the ATO OBU or by the locomotive driver, bearing in mind the stated priority of "safety before punctuality before economic efficiency". In this context, "implementation" means transmitting traction/brake demands via SS139 or the drive/brake lever to the TCMS, which controls the vehicle's braking and drive systems. At the same time, the train driver or the ATO-OBU keeps an eye on the train status and operates the doors, etc. in accordance with the procedural steps

The external control loop includes all those infrastructure elements that can control or influence the vehicle's driving behaviour. RCS carries out the network optimisation. On this basis, it generates the instructions for each individual vehicle which are then transmitted to the ATO-OBUs via ATO-TS. These instructions are planned and transmitted afresh as required. So as to ensure optimum network usage and operational stability, the ATO-OBU must carry out the instructions precisely and without delay. In addition to the RCS, the control loop also includes all those train control elements that affect the way in which the RCS exercises control.

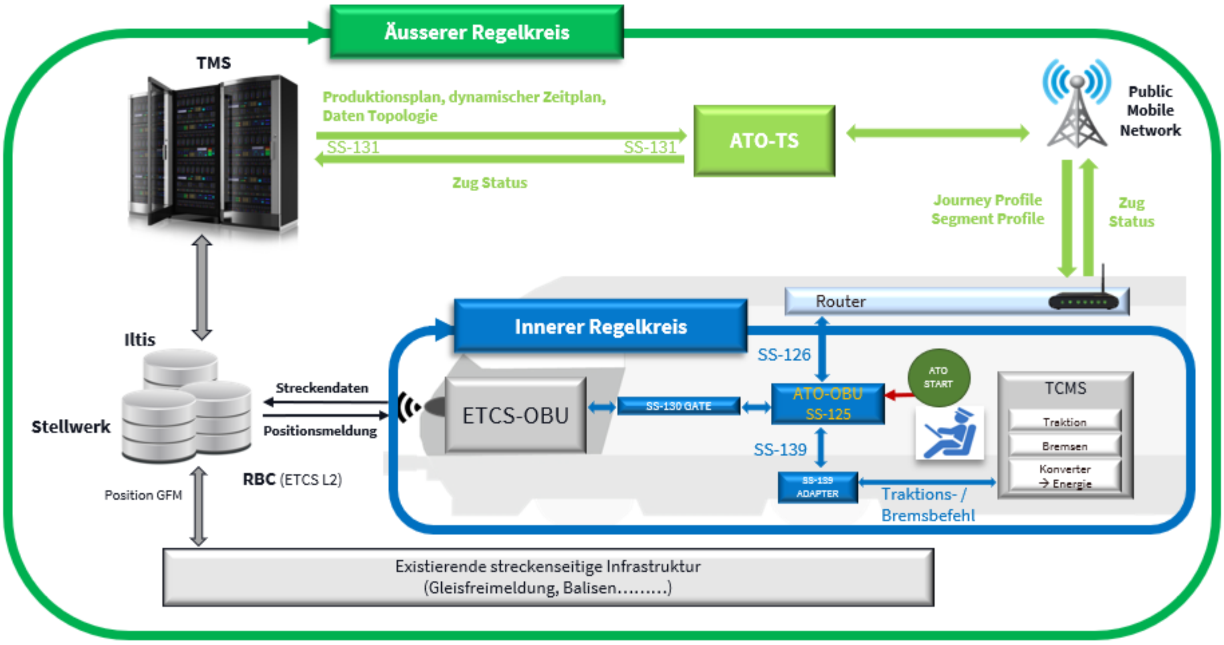

Figure 19 The system architecture illustrating the control loops

The figure illustrates the generic system architecture and shows the elements which make up the internal control loop (in blue) and the external control loop (in green).

4.2.7.2. Driving with live data from the RCS

Live data from the RCS (timetable data, forecast data) is used by the ATO-TS as the basis for creating journey profiles. If, for example, a scheduled arrival time cannot be achieved based on the RCS forecast, the RCS will transmit a new production specification to the ATO-TS. The ATO-TS converts the target into a new journey profile with a correspondingly changed arrival time and transmits it to the ATO-OBU. There is no systematic consideration of the latency times between the RCS and the ATO-OBU, or of their implications.

Because the known position of the train, for example, is relatively imprecise with today's RCS, this can produce certain uncertainties in the forecast.

Observations:

- Journeys whose journey profiles are based on RCS live data taking place without any noticeable anomalies and under normal, scheduled operating conditions.
- However, in dynamic operational situations where delays and changes affect the timetable, the acceleration or braking which occurs following receipt of a journey profile update and the re-calculation of that profile is perceived as "unsteady driving behaviour".
- Sometimes, due to the RCS <-> ATO-OBU control loop, it was observed that delays resulted in the RCS's forecast arrival time being re-calculated. The consequence was that,

after receiving the relevant journey profile, the ATO OBU calculated an even slower journey profile. This effect sometimes built up.

- To ensure optimum operations and operational stability, further test runs need to be carried out to investigate the extent to which the internal and external control loops are interdependent (see Figure 19).
- The forecast arrival time is actively calculated in the ATO OBU based on the current vehicle characteristics. Thus, a vehicle-specific calculation of the forecast taking account of the actual journey profile in the RCS could significantly improve accuracy.

From the above observations it follows that special attention needs to be paid to the effects on passenger comfort and on the external control loop (ATO-OBU interaction with TMS) at the point in time during the journey when the journey profile update is issued. This requires analytical investigations and a series of further test runs to verify these analytical results. The extent to which this depends on the vehicle type (behaviour) and any other conditions (e.g. maximum acceleration, weight, ...) must also be investigated, as there is considerable potential for optimisation when using this data. As regards the target scenario of the SR40 system, this means:

- A suitable control algorithm must be developed, tested and optimised for the interaction between the internal (TCMS, ATO-OBU, etc.) and external (TMS, railway system etc.) control loops so that changes in driving behaviour can take place smoothly.
- This requires coordination of the corresponding requirements between Processes & Requirements, TMS development and ATO. This is needed in order to define suitable vehicle-specific parameters for corresponding requirements for the overall system and to ensure that a continuously improved control loop can be realised on the basis of the resulting data. From a certain point in time, this will not be possible without employing artificial intelligence
- The optimisation of system technologies, harmonisation of interfaces and protocols (e.g. OCORA) as well as the systemic expansion of the data volume and data density, all of which is already under consideration, must be driven forward in order to benefit from the potential of the control loops as outlined above.

It is also necessary to examine the optimum number of timing points between two stopping points. Too many timing points could lead to unsteady driving behaviour and increased energy consumption.

5. Conclusion

This section summarises the knowledge gained from the test runs on the Lausanne-Villeneuve line as part of ATO2Basic, as well as SBB's runs in preparation for the Shift2Rail DB Cargo ATO Freight Demonstrator (see Bericht DB Cargo Pilot Vorbereitung (Report, DB Cargo Pilot, Preparation) Sion-Sierre).

Thus, this section contains what is currently known at the time of publication about the characteristics and the potential for using ATO Automation Level GoA2 for regional services. The characteristics of ATO listed below are discussed in detail in the subsequent sub-sections:

- The applicability of the draft TSI standards to Swiss railway operations
- Driving behaviour
- Punctuality
- Stopping position
- Energy saving
- Passenger comfort
- The benefits for railway operations and locomotive drivers

5.1. Achievement of the phase objectives

Objective		Remarks
ATO operation with all ATO-OBU interfaces in accordance with the draft TSI standard (as far as technically feasible)	✔	The live tests were carried out with an appropriately equipped ATO-OBU functional sample.
Rail operations with bidirectional interface to the ATO-TS and thus implementation of dynamic timetable specifications from the RCS	✔	Train movements were carried out with appropriate directives; implementation was demonstrated, and potential for improvement was identified
Further-reaching driving behaviour observations with extended functionality compared to Phase 1; determining potential	✔	These observations were carried out and are described in this document.
To verify that ATO functionality does not adversely affect railway operations	✔	No adverse effects on railway operations were identified, but there is potential for optimisation.
PoC, that ATO GoA2 with ETCS connection according to Subset 130 can already be implemented with ETCS Baseline 2.3.0d.	✔	Essentially, ATO with GoA2 is already possible with Baseline 2.3.0.d.

Table 8 Achievement of the phase objectives – a summary

5.2. Applicability of the draft TSI standards to Swiss railway operations

From today's perspective, using ATO together with TSI-compliant interfaces will not – provided certain conditions (analyses and operational testing of the control loop dependency and possible adjustments to the specifications) are observed – adversely affect Swiss railway operations. Phase 2 of the ATO2Basic project has already identified that using ATO has the potential to deliver major benefits.

However, a number of points have been identified which must be taken into account in the proposed specification for the TSI standard (see section 0). Various points which are absolutely essential and which also contain the clear potential for improving the proposed specifications for the TSI standard have already been reported back to the Shift2Rail working group. The aim is to optimise the interplay between the ATO and the TMS systems in general, but especially as regards the future TMS.

The definitive TSI 2022 standards envisage the ATO OBU interacting with an ETCS OBU with a Baseline 3.7 software level (3.6 plus ATO interface and DMI adjustments for ATO information) or higher. In contrast to this, it was demonstrated that ATO-GoA2 operation is already possible with an ETCS-OBU equipped with the current baseline 2.3.0.d, and that it can make a major contribution to improving the stability of the timetable and increasing node capacity while at the same time achieving maximum energy-saving potential. The introduction of ATO does not require the ETCS on-board equipment fitted to the existing ETCS vehicle fleet operating in Switzerland to be upgraded.

5.3. Driving behaviour

ATO shows that it can adhere very precisely to the journey profile. Given appropriate timings to adhere to, an ATO-controlled train will run very close to the speed and braking curves specified by ETCS.

There is optimisation potential in the application of the various braking curves. The ETCS warning curve was introduced in order to inform the driver of a manually controlled train in good time of an impending emergency braking manoeuvre. Once ATO has been successfully introduced, the warning curve could be dispensed with in order to achieve the maximum gain in capacity. The important thing here is that the ATO-OBU control mechanism does not initiate emergency braking.

5.4. Punctuality

The ATO-OBU is controlled continuously and very precisely, so there is only a minimal difference between the scheduled arrival time (according to journey profile) and the actual arrival time. This assumes that the train's departure time from the previous stopping point and the maximum permitted line speed make it possible to meet the scheduled arrival time.

Even in the event of a delay, the ATO-OBU will try to arrive on time, driving to the next stop as energy-efficiently as possible and in the manner described in section 5.3. This will reduce the delay on that particular section of the route as much as possible.

5.5. Stopping position

Achievement of the smartrail 4.0 requirements by the functional model (assuming appropriately positioned balises) is already put at 97%. All the objectives set out in the locomotive driver training documents can already be met with the existing infrastructure.

5.6. Energy saving

Depending on the vehicle, it is possible to save energy by, for example, reducing acceleration and braking frequency but this may have implications for punctuality, depending on what the timetable specifies.

The potential for making energy savings of up to 37% was observed on the (individual) runs carried out for comparing ATO and manual driving. It was also observed that when the locomotive driver focused on energy-saving driving, they were – understandably – not able to match the precision achieved by ATO as regards arrival time and position. (See Reference 1)

5.7. Dynamic driving/braking behaviour

The ATO team is not aware of any specific definition of passenger comfort based on dynamic ride/braking behaviour that could be verified by measurable parameters.

The definition given in the procurement documents cannot be used for this since, according to that definition, the relevant values are averaged over longer distances and do not take into account immediate driving behaviour when starting off and braking.

The test team's subjective impression from the ATO runs was that there were hardly any differences between the ATO runs and the scheduled regional journeys. The most that can be said is that the team gained the impression that manual driving was smoother shortly after departure and shortly before stopping. Rapid acceleration and sharp braking were also experienced when making up for delays. When driving across points, moreover, ATO also made use – when required – of the maximum permitted speed, whereas the runs under manual control at reduced speeds was subjectively more comfortable.

5.8. The benefits for railway operations and locomotive drivers

5.8.1. Benefits of ATO identified by industry and their evaluation

As early as 2017, industry suggested – based an analysis of various projects – that ATO had the following potential; see Reference 2 (Presentation ATO/DAS over ETCS – The way towards unattended operation for Main Lines – Alstom, Feb. 2017):

- **Up to 42% energy saving potential for regional services**
- **Up to 30% capacity gain**

5.8.1.1. Evaluating the energy saving potential:

An energy saving potential of up to a maximum of 37% was observed from individual measurements during the test runs. The OBU used in ATO2Basic Phase 2 was a functional model, operating to draft standards of the interface specifications; without these specifications it did not enjoy any prototype or product status. Against this background, industry's statement in section 5.8.1, above would appear to be realistic or possible, at least on certain sections of line. What the average realistic level of energy savings can only be demonstrated after a lengthier operational trial (and then only for those sections of the line).

5.8.1.2. Evaluating the increase in capacity (stability, node capacity)

After observing the precision resulting from ATO control operating at the system limits (e.g. the closeness of the profile driven to the braking curve, even with poor adhesion conditions), the potential suggested by industry for increasing capacity is considered realistic. The precision with which an ATO-controlled train stops at the required position can also contribute to timetable stability. Additional benefits arise in particular from the fact that the passenger changeover process can be improved by appropriate guidance measures on the platforms, thus optimising the time for boarding and alighting.

5.8.2. Evaluating the potential of ATO GoA2 to reduce the locomotive driver's workload

ATO has the potential to be punctual, precise (stopping position) and energy efficient all at the same time. The ATO-OBU continuously calculates an optimum driving profile throughout the entire journey. Keeping a constant and repeated watch on all three parameters (time, stopping position, energy) throughout their shift in addition to their safety tasks is a challenging task for the locomotive driver. ATO can assist the drivers and greatly reduce their workload, especially in nodes.

Under ATO control, the train can be driven precisely and close to the train control system's speed curves. Driving close to the limit of the "yellow" (brake advisory) and "orange" (warning) area of ETCS requires a high degree of concentration from the locomotive driver, something which is almost impossible to sustain over a lengthy period.

By using ATO, the locomotive drivers can reduce their workload in repetitive and/or permanently demanding situations and can thus devote themselves to the most essential and important tasks (monitoring the line ahead and looking after the passengers), tasks of which even ATO GoA2 cannot relieve them. The driver is also relieved of the consequences of any delays if the journey is under ATO control. Additional requirements and situations in which the locomotive driver may come under stress due to node capacity expansion or to a future increase in the range of services can be alleviated by ATO.

It has yet to be determined where and when (place, time) ATO GoA2 is to be employed so that the locomotive driver's workload can be reduced, allowing them to give their full attention to safety in accordance with the instruction "Safety before punctuality before economy" (e.g: at nodes during rush hour) and yet without any loss of concentration.

6. Outlook

Further Phase 2 test runs, as well as the ATO2Basic project's already scheduled Phases 3 and 4 (operational testing) had to be cancelled due to the 2020 budget cutbacks and to the reduced funding available in the LV (SLA) 21-24 period.

It is vital that the activities planned for Phase 3 (plus Phase 4, which is scheduled to be a commercial operational trial) be carried out while the Shift2Rail standards are being finalised. It is in these phases that the definitive standards are to be evaluated, that the ability of locomotive drivers to apply them is to be demonstrated and that representative measurements are to be made through imposing performance specifications on industry, all of which must be undertaken before the specifications in the TSI are approved.

Those topic areas – already known from Phase 2 and requiring analysis in Phase 3 – are as follows:

- Comprehensive analysis of the control algorithm, for example in connection with the traction-less phase in neutral sections
- Analysis of the minimum requirements for adapting ETCS project design rules on lines with ATO operation (e.g. additional balise positions), so that they can be taken into account when existing L2 lines are upgraded and/or during L2 improvements
- In-depth examination of stopping position accuracy and detailed analysis of OBU and infrastructure data to identify the reasons why trains stop at positions other than those specified
- Determining those specific elements of the control algorithm on which vehicles are dependent so that the journey profile can be optimised
- Systematic investigation of driving behaviour when adhesion is poor
- Detailed comparative energy measurements, detailed analyses of the mechanism of action, comparison of the federal government's and SBB's energy-saving strategies
- Analysis of the infrastructure-specific and vehicle-specific potential for optimisation

Independently of ATO2Basic, test runs with a freight train are being carried out as part of the Shift2Rail/DB Cargo "IP5 ATO GOA2 Cargo Demonstrator" project, which is analysing the specifications for its use in a freight train. To review the test infrastructure, especially the segment profiles, verification runs with the vehicle used for ATO2Basic were carried out beforehand. The resulting observations were set out in a separate document as part of SBB's support for this pilot which DB Cargo had defined (see the document entitled Bericht DB Cargo Pilot Vorbereitung (Report, DB Cargo Pilot, Preparation) Sion-Sierre). The results of these verification runs can be used to underpin this report

7. Comments specifically pertaining to SBB

During the test runs, it was observed that the current ATO-OBU functional model reacts very sensitively to inconsistencies in the segment profiles:

- At the end of one segment profile (SP) there was a gradient which extended beyond the end of the SP. This caused the OBU to switch over to "Disengaged"
- If balise data was missing from the segment profile (SP), the OBU switched over to "Disengaged" mode. But not in all cases.

Because the test runs have been cancelled due to budget cuts, and also because the ATO-OBU is a development stage functional model, these phenomena could not be investigated in detail with the manufacturer. However, even with commercial products produced subsequently by different manufacturers the complete elimination of errors can never be guaranteed.

Special attention should therefore be paid to optimising both the degree of automation and the basic data for generating the segment profiles. The reasons for the inconsistencies and anomalies which occurred should be traced back to their sources (i.e. the root causes). Incorrect basic data should be detected and corrected as early as possible in the process chain and checked before being sent to the OBU. It is important that the topology data used to create segment profiles is of a sufficiently high quality when ATO is introduced.

8. Various issues discovered in the standards

In the course of the project, various issues and potential for improving the specifications were identified (energy management, TMS control such as max. acceleration values); these were reported back to Shift2Rail and are currently being discussed or processed. These findings can basically be divided into the following groups:

a. Lack of functionality

While reviewing the draft standards in preparation for the ATO2Basic Phase 2 tests, a number of ideas for tests relating to complex TMS control scenarios could not be implemented as actual test cases since the required functionality was not present in the draft standards. Said required functionality has been assigned to this group.

b. Need for testing (not covered by functional models)

During the preparatory work for the tests, certain issues arose which, according to those who had identified these issues, would need to be tested; however, because the relevant functionality had not been implemented (for example, the lack of a DMI conforming to the standard) they could not be tested. Failure to test these issues due to the appropriate functionality not being implemented is assigned to this group.

c. Conspicuous features noticed during the test runs

Issues assigned to this group were identified during the test runs and reported back to Shift2Rail.

d. Suggestions for improvement / comments unrelated to ATO2Basic

Questions which arose while reviewing the standards, plus comments or any potential for improvement which was revealed (incl. requirements / adjustments identified by the locomotive drivers) and which were fed back to Shift2Rail without any direct reference to ATO2Basic pilots. At the same time, several points were identified which are essential for locomotive drivers to be able to accept ATO; also, ATO performance must be improved to an appropriate extent without any corresponding upgrading of ATO OBU (or, in particular, of its software).

9. Reference documents

1. Bericht DB Cargo Pilot Vorbereitung (Report, DB Cargo Pilot, Preparation) Sion-Sierre
2. Presentation ATO/DAS over ETCS – The way towards unattended operation for Main Lines – Alstom, Feb. 2017
3. ATO2Basic Phase 2 test cases V.1
4. Test report 2019 published on the smartrail 4.0 website