Addendum to the ATO exploratory study Groningen

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Readers' guide

This report is an addendum to the Final Report ATO exploratory study Groningen (phase 1 and 2) that was released in September 2020. This report contains the results, conclusions and recommendations of additional tests (phase 2B) executed in July/August 2021. For general information about ATO, the general background and set up of the study we refer to the original report (link: Final Report ATO exploratory study Groningen).

TABLE OF CONTENTS

Management summary

During the previous test phases the basic functions of an ATO system have been tested. Phase 2B has been introduced to test more specific functions and potential of ATO:

- To demonstrate that the ATO system can drive according to a timetable.
- To demonstrate that the ATO system can cope with changes in the route.
- To demonstrate that the ATO system can cope with delays.
- To investigate what the potential effect of ATO are on energy usage.

This test was executed on a class B ATP equipped line (ATBNG). This system has no interface specification available between the ATO-system and the ATP-system. For the phase 2B tests the exact same train was used as for phase 2 to get consistent test results and to be able to compare the results for both phases. The ATO system used for phase 2B was different then the version used for phase 2 and it completely relied on ATBNG data for positioning and signal aspects. During the previous phases positioning was determined by GPS combined with the odometer.

The tested solution is capable of executing the requested advanced functionalities. The test train was able to halt at the stopping location (+/- 3 meters) and at the right time. Updates were correctly incorporated into the speed profile when send in advance and within reasonable limits. This applies for timetable updates, track changes and segment profile updates. Also a clear drop in energy usage was observed between the different ATO driving modes, driving full speed and driving with an economic driving style combined with a higher buffer.

All requested advanced functionalities have been witnessed and seen working. But the results have not been consistent. Which was expected due to the fact that we are dealing with a prototype. The positioning system relied heavily on ATBNG and further optimisation is still possible in the way certain functions are being implemented and executed. Compared to the phase 2 tests we were able to gather more data and executed test runs driving according to a timetable with an energy reduction in high buffer timetables.
Overall we can conclude that this ATO system proved to have the potential to execute basic and advanced functionality under ATBNG but also that it was difficult to tune the ATO-system with the ATBNG-system which resulted in signalling information and positioning sometimes being processed incorrectly. Based on this ATO system, we conclude that a significant development step is still necessary for a stable and reliable ATO-system using information from ATBNG.

Background and objective

1.1 Background

During the previous test phases the basic functions of an ATO system have been tested. Phase 2B has been introduced to test more specific functions and potential of ATO.

1.2 Objective

The objective of this exploratory study is:

- To demonstrate that the ATO system can drive according to a timetable.
- To demonstrate that the ATO system can cope with changes in the route.
- To demonstrate that the ATO system can cope with delays.
- To investigate what the potential effect of ATO are on energy usage.

1.3 Setup

For the phase 2B tests the exact same train was used as for phase 2 to get consistent test results and to be able to compare the results for both phases.
Due to the requested advanced functions the ATO system used for phase 2B was different then the version used for phase 2 and it completely relied on ATBNG data for positioning and signal aspects. During the previous phase 2 positioning was determined by GPS combined with the odometer.
A safety file has been drawn up for carrying out the tests and with this an exemption has been requested and obtained from IL&T.

Phase 2B resulted in:

- 6 periods with in total 21 nights of testing
- Total of 186 test runs
- Approximately 3800 kilometres driven under ATO

The objectives have been processed in various test cases and these have been analysed per case
An overview of the Test periods and Test cases can be found in the appendix.

2 Report and results of the live test runs

2.1 Analysis approach

2.1.1 Sources

The analysis on Phase 2B is based on various data sources. Data quality has been improved since the early Phase 2: higher availability, accurate speed measurement and same clock speed. Sources have been merged:

- Main data sources are Automatic Ride Registration, vehicle controller log, and ATO log.
- Frequency varies from 1 to 20 Hz. For analyses, 1 Hz is sufficient and sources are aggregated to 1s resolution.
- During the tests, clocks were not synchronised. For merging, the off-sets were determined on the basis of speed, which is well measured in all sources.
- Test run number and Traffic control train number were joined for quick reference.

2.1.2 Test run numbers

Test runs are numbered in this system:

- Letter A-F refers to the 6 test periods. The first periods were largely used to make the ATO system working, are less representative for testing results and face some lacking data. Therefore the analyses focussed on the periods D, E and F (end July and early August). As far as periods B and C are included, they are separately visible.
- The next position tells the night of a period: 1 is the first night etc.
- The last two figures number the runs within the night. Odd numbers (01, 03 etc.) relate to westbound test runs, even numbers to eastbound runs. The number does not change after a stop in Zuidhorn or Grijpskerk.
- Example: D3-02: Test period D, 3rd night, run 2

2.1.3 Activities

Many research questions require actual train activity times. These are determined this way:

- Departure (Hoogkerk Aansluiting, Zuidhorn, Grijpskerk, Buitenpost) is the last second after standstill where speed is below 0,1 km/h.
- Passage (Hoendiep, Grijpskerk Aansluiting) is the moment that train position equals a certain distance after the latest ATBNG beacon.
- Arrival (same locations as departure) is the first second where speed drops below 0,1 km/h.

Departure and passage count as “under ATO” when ATO is Engaged in that second. Upon arrival, the ATO State tends to change into Ready just before standstill; therefore, the state of 5s earlier is taken to determine whether arrival is realised under ATO.

Around some stops, a train makes a second (generally unintended) stop at short distance from the main stop. In these cases, arrival/departure determination is less straightforward and deviations in running time may occur.

Stopping position is determined from ARR data: distance according to train odometer after passage of ATBNG beacon. This has an estimated measuring deviation of just meters.

2.1.4 Signals or ATBNG

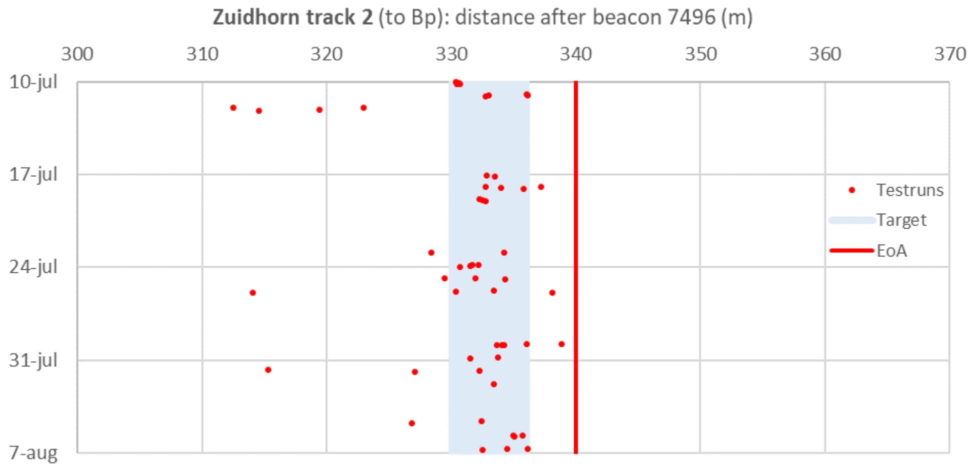
The test plan mentions a distinction between two test scenarios: obeying restrictive line-side signals versus braking later when the ATBNG curve requires so. But for GTW rolling stock at the relatively high line speeds at Buitenpost-Hoogkerk, the ATBNG curve is at least as restrictive as the signals. Hence, ignoring line-side signals does not yield any additional performing space. The theoretical distinction does not show up in this test setup and is left out of the analyses.

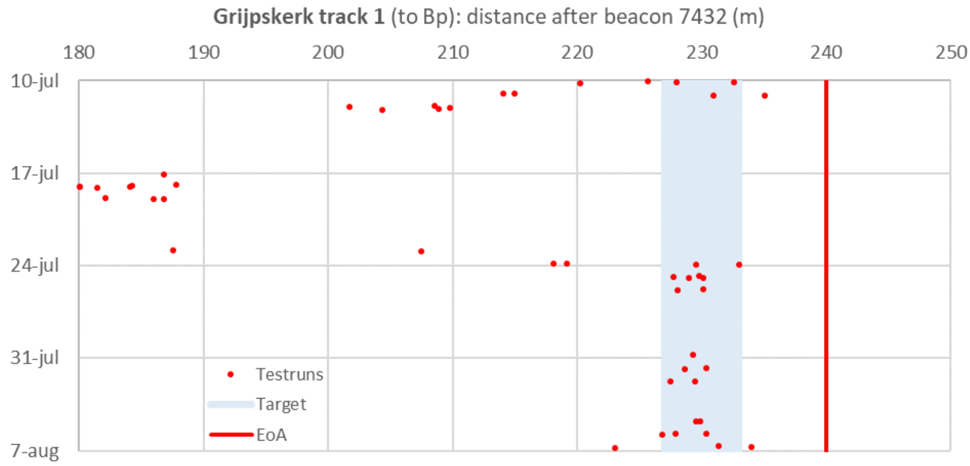
2.2 Analysis of the test cases

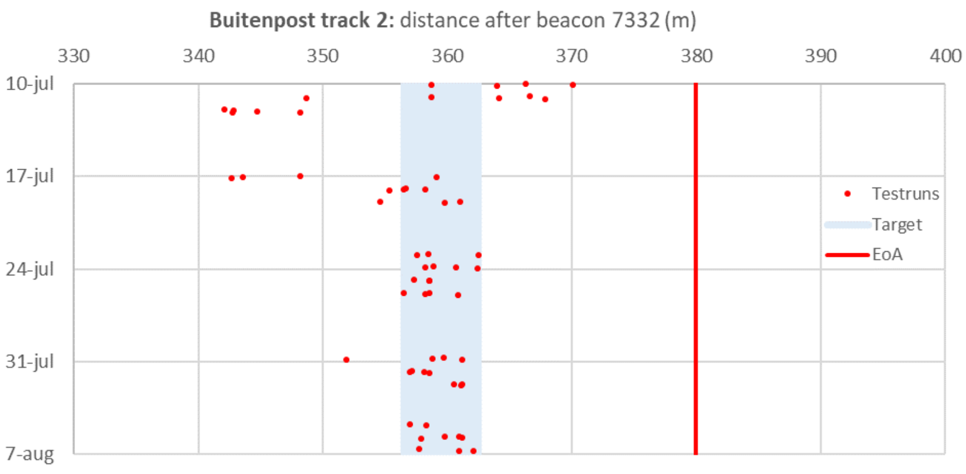
1a Normal run with planned stop (accurate stopping)

1a1 Approach of a planned stop at EoA

On three locations (coincidentally all westbound arrivals) the train makes a planned stop close to the red signal. The graphs below show the stopping position during the test period, relative to the latest passed beacon. The blue bar indicates the position that is judged correct by local observations during test nights plus and minus a tolerance of 3 meters. This is the best achieved accuracy on some locations in later weekends. The figures below have a range of 70 meters. In some occasions the stopping location was outside this range with explainable causes.



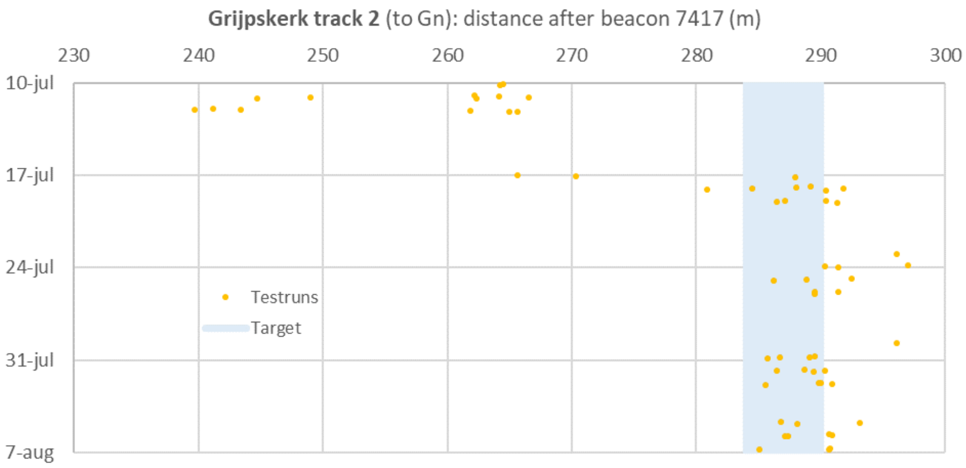


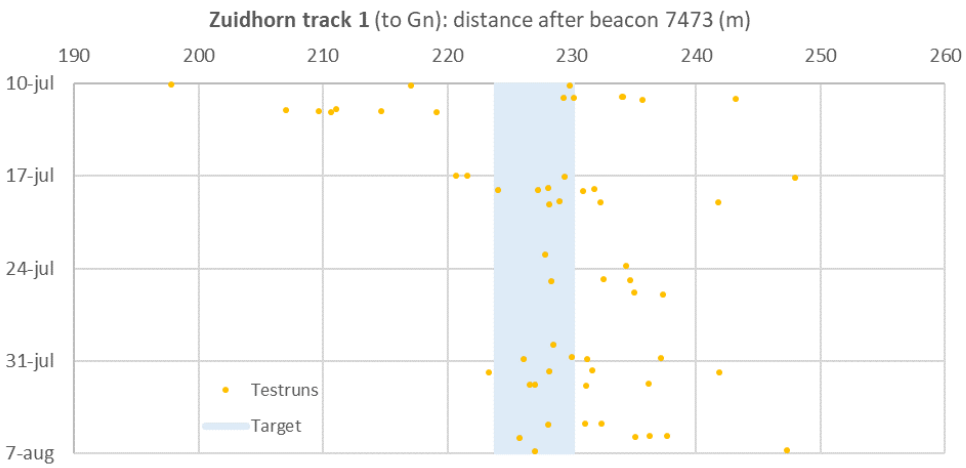


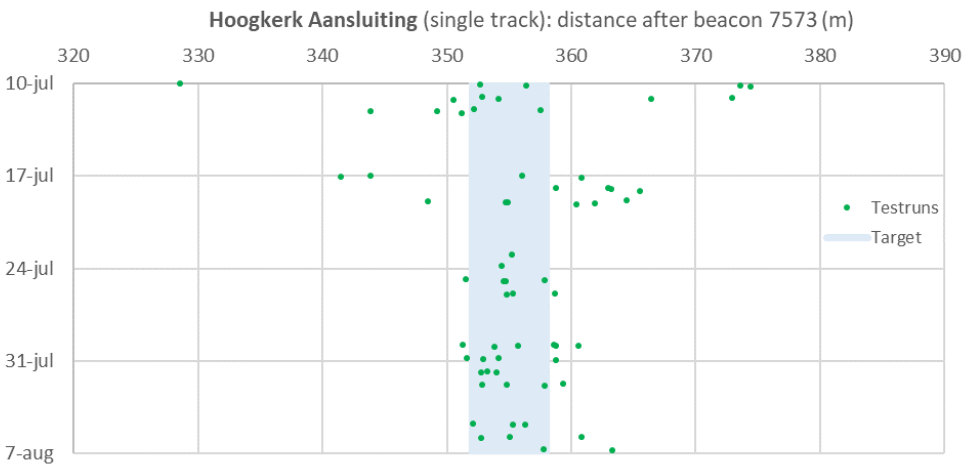
The accuracy clearly improves over the weeks, outliers become exceptional and by the beginning of August most trains end within 3 meters from target position. In the EoA scenario, trains end under release speed (ATO uses 9 km/h) and perhaps this eases a well-aimed final deceleration tot stopping.

1a2 Approach of a planned stop not near the EoA

All eastbound arrivals are located further from EoA. Grijpskerk and Zuidhorn approximately 100m before an EoA are drawn yellow, close to the braking curve but not under release speed. Hoogkerk has a distance to go of a few kilometres, displayed with green dots.







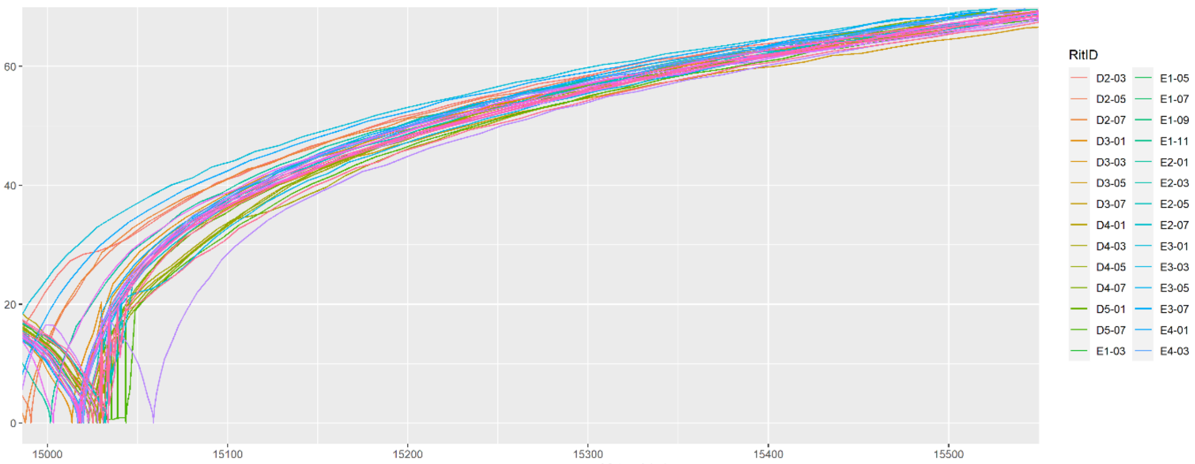
Overall, position accuracy seems to be a little more difficult when stopping not at EoA: a lower share manages to stop within 3m from target position and a relatively high number of runs stop too far. Two low values in Grijpskerk in the F-weekend were caused by loss of ATBNG connection; apparently this connection is essential for accurate stopping. Performance without EoA seems worse than achieved in December 2019 (Vierverlaten all runs within 1m from target).

1a3 With planned stop at EoA

1a3a Departure after a stop on an ATBNG loop

ATBNG loops are common practice on the test line, they are giving the train a constant update about the signal aspect ahead. Departure from Zuidhorn to Grijpskerk is used as an example. The speed profile below displays a fluent line for most runs, so ATO is able to accelerate comfortably and quickly.

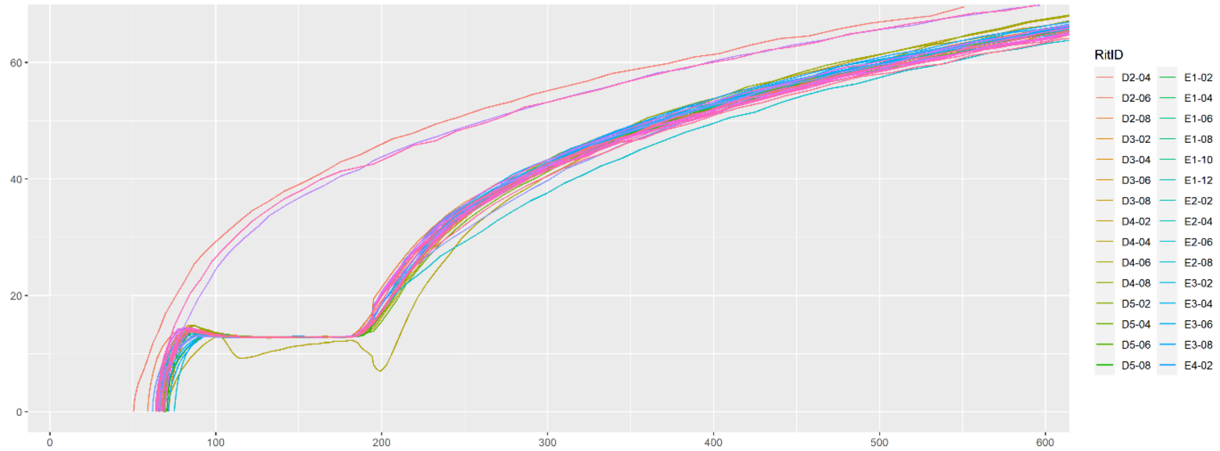
All westbound test runs in period D-F, 2nd acceleration



1a3b Departure after a stop not on an ATBNG loop

A situation without loop is found in Buitenpost, where trains turn on track 2 and depart in the unusual direction. The graph below show that trains accelerate to release speed (by ATO very consistently translated to 13.0 km/h). After passing the next beacon, further speeding up takes place.

All eastbound test runs in period D-F, first onset



Note that a few runs accelerate to higher speed immediately. These were changed to track 1, which is the regular departure platform for Groningen equipped with an ATBNG loop.

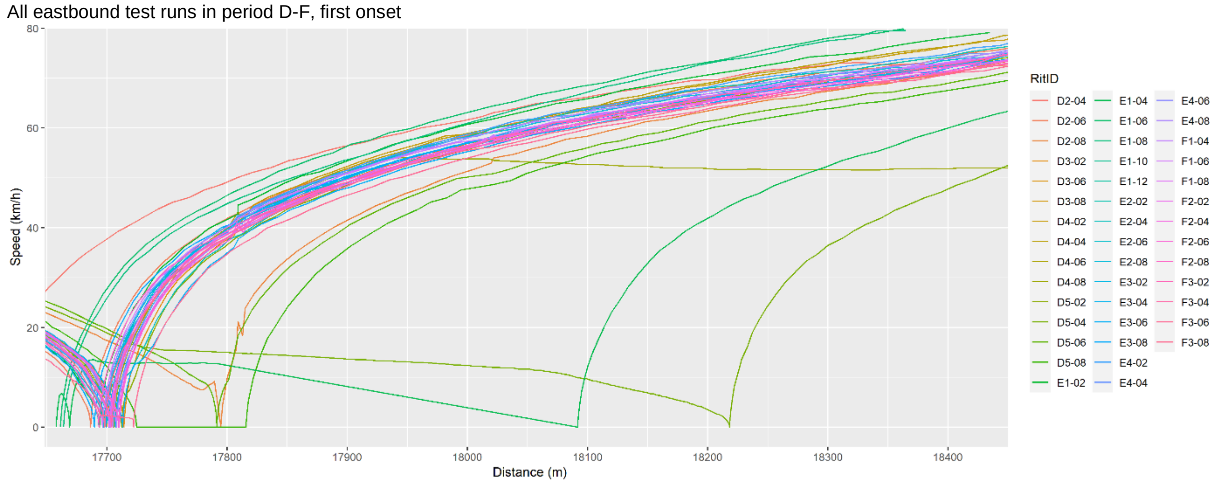
Hoogkerk Aansluiting has no ATBNG loop but trains stop so close to the signal, that release speed is hardly limiting. Nevertheless, an interesting difference is worth mentioning:

- The first run of each night coming from Groningen has a release speed of 10.5 km/h until passing beacon 7582 at signal 414.
- All further runs, arriving from direction of Zuidhorn and turning at Hoogkerk Aansluiting, have a release speed of 13.0 km/h just as the trains turning at Buitenpost mentioned above.

1a3c Departure after a stop not near an EoA

In Zuidhorn to Groningen trains already have their MA before arrival. Not surprisingly, trains generally make a smooth acceleration.

All eastbound test runs in period D-F, first onset



1b Normal run with short headway (accurate driving)

Although the title may suggest another train running downstream, this item focusses on accurate driving, with the Journey Profile as operational goal. The research plan mentions only two scenario's (1b1: time tolerance 0s and 1b2: 120s) but the real tests were more diverse, with different window sizes applied at various locations over time. The subject is looked at from various perspectives. The tables below give a couple of figures:

- Number of arrivals in the group.

- Percentage realised within or at the borders of the window. JP gives a final arrival time and the window specifies to what extend *early* arrival is allowed. Late arrival is not allowed, so no window applies to the upper side.
- Because of controlling and measuring deviations, the next column evaluates correctness with an additional 10 seconds tolerance *at both sides*.
- When even this window with extra tolerance is not met, the next question is whether the train was early or late. Percentage early is displayed red: ATO was not given any minimum speed requirements so early arrival can always be avoided.
- Percentage unnecessarily late trains. Late arrival or passage can be inevitable when previous departure was late. Trains running as fast as possible are excluded from the percentage 'too late' because ATO did what it could and is not considered wrong. .

In a top-down approach, the first table just distinguishes between arrival and passage Timing Points. Passage points perform better; arrivals have higher shares beyond both borders of the window (both early and late). This relates to the fact that passages are often allowed wider windows than arrivals, as can be seen in the following tables.

Type of Activity	Count	In window	±10"	Too early	Too late
Arrival	186	26%	49%	22%	14%
Passage	105	56%	69%	10%	7%

The next two tables split on time arriving and passing by window size. Rare window sizes are written in grey. In general it can be said: the wider the window, the more trains in it and the fewer trains too early. The number of late trains does not decrease, which is understandable because the window only applies to earliness. The last column ('Same ref') compares on time running to a constant reference: the share of runs between -40s and +10s of the specified time. Then, smaller windows lead to better performance.

Arrival window	Count	In window	±10"	Too early	Too late	Same ref.
0	35	6%	26%	51%	11%	77%
10	7	0%	14%	57%	29%	71%
20	2	0%	100%	0%	0%	100%
30	136	29%	54%	14%	15%	54%
240	4	100%	100%	0%	0%	0%
330	2	100%	100%	0%	0%	50%

Passage window	Count	In window	±10"	Too early	Too late	Same ref.
0	9	0%	33%	56%	0%	89%
30	34	44%	71%	6%	15%	71%
60	39	72%	74%	3%	3%	64%
120	23	70%	70%	9%	4%	30%

The next tables look at individual timing points, one table for each direction. The share of early arrivals is fairly high. When late, a result is only considered wrong when the actual running time is longer than the median of all running times on that stretch; otherwise ATO did its best. When running time exceeds that median, however, the result is called 'too late' and the absolute number is added between brackets. For some cases, the relation with the median running time could not be made because of manual driving or incomplete information. Where possible, ATO driving behaviour before lateness is described.

Westbound	Count	In window	±10"	Too early	Too late		Driving behaviour before arriving too late
Hoendiep	26	62%	65%	12%	0%		
Zuidhorn	30	23%	50%	20%	13%	(4)	Pass TP Hdp, fail TP Zh (see separate table)
Grijpskerk Aansl.	26	65%	77%	4%	4%	(1)	
Grijpskerk	29	45%	59%	10%	17%	(5)	E3-01, F1-05 run hardly 100 km/h, coasting
Buitenpost	36	22%	28%	44%	8%	(3)	

Eastbound	Count	In window	±10"	Too early	Too late		Driving behaviour before arriving too late
Grijpskerk	32	13%	63%	3%	13%	(4)	F3-08 slower, coasting from 120 km/h
Grijpskerk Aansl.	28	46%	57%	4%	21%	(6)	
Zuidhorn	29	24%	48%	24%	17%	(5)	
Hoendiep	25	52%	76%	20%	0%		
Hoogkerk Aansl.	30	30%	53%	27%	17%	(5)	JP update experiment led to infeasible JP

Looking at individual stations, only 1 early arrival (3%) in Grijpskerk eastbound is striking. This is a result of the JP timetable: scheduled running time is in most cases 7.0 mins whereas the minimal operational running time is 7.5 mins so arriving early is unlikely. The high share of 63% arriving more or less on time is only possible by leaving Buitenpost too early.

Part of delays in the table are due to specific JP circumstances:

- Hoogkerk-Zuidhorn is enlightened with two examples in the table below. Very early departure force these runs to start off slowly. As a result, the train loses time in accelerating after Hoendiep. With faster driving on the first part or otherwise passing Hoendiep at a higher speed, arrival delay Zuidhorn could have been reduced.
- In the other direction Zuidhorn-Hoogkerk, JP passing time Hoendiep is postponed by 5 minutes (see section 3b) but without changing the target time at Hoogkerk. This results in a negative scheduled running time from Hoendiep to Hoogkerk, which is obviously infeasible. The passing targets at Hoendiep are met, but trains arrive late in Hoogkerk.

Apart from these cases, a few other runs are coasting while late. Together with a large share of early arrivals, this seems to indicate room for improvement of the ATO algorithm: more energy-efficient coasting when running on time, always cruising at line speed when late.

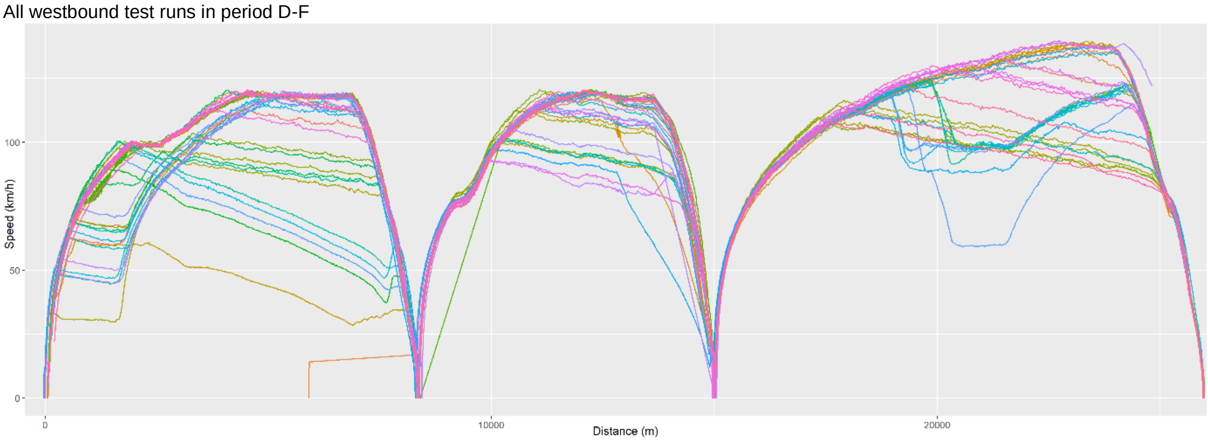
Test run	Hgka D		ATO driving strategy	Hdp P		ATO driving strategy	Zh A	
	win-dow	actual (s)		win-dow	actual (s)		win-dow	actual (s)
F1-01	0	-60	50 km/h, coasting	60	-45	acc., cruise 120 km/h, brake	30	+41
F1-05	0	-45	50 km/h, coasting	0	-14	acc., cruise 120 km/h, brake	0	+30

Test runs D2-06 and D3-06 had a “departure delay” at Grijpskerk of 3589 and 3596 s, respectively, indicating an hour deviation in the JP. Although this had no influence on passage or arrival output measures, this may be relevant for quality control.

1c Normal run with fixed speed restriction

Regular line speeds of 100, 120 and 140 km/h are well respected (figures below). The transition between 120 and 140 km/h is located close to Grijpskerk, so trains face either of both speed limits. Towards the red signal at Buitenpost, signals impose a restriction of 80 km/h, which is followed by all trains.

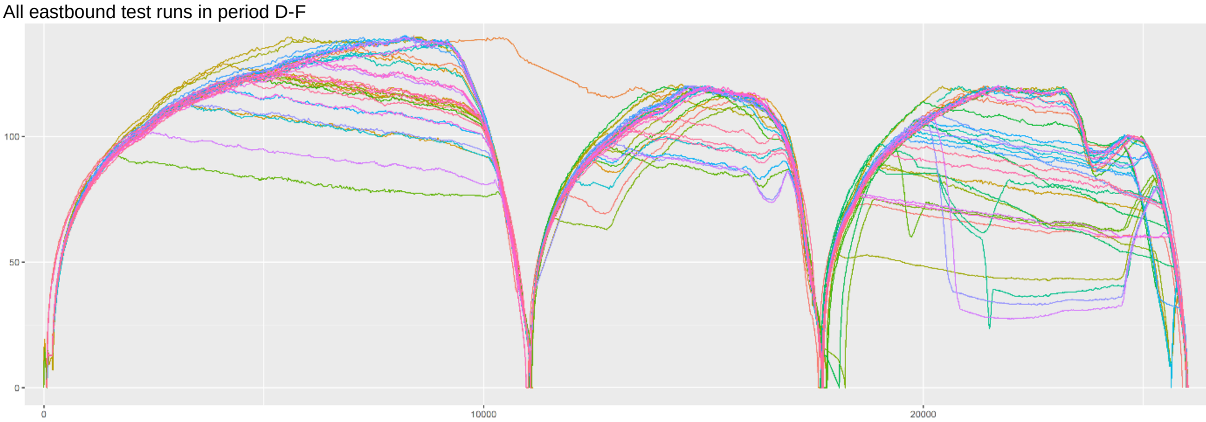
All westbound test runs in period D-F



The transition between 100 and 120 km/h is more interesting, located on open track.

- In westbound direction, the restriction of 100 km/h at the beginning of the line is held by all trains until further acceleration to 120 km/h is allowed (see above).
- Eastbound, the speed descent from 120 to 100 km/h is not handled properly: speeds consistently drop too deeply (~90 km/h) and then reaccelerate. Here is room for improvement.

All eastbound test runs in period D-F



1d Normal run with switch related speed restriction

The only switch related restriction (speed depending on the route) is after departure from Buitenpost track 2. The limit of 80 km/h is visible in the loggings. Due to absence of an ATBNG loop and limited rolling stock traction force, the allowed speed raises to 140 km/h just before the train reaches 80 km/h. Hence, speed runs up smoothly from release speed to top speed (figure above).

1e Normal run with slope

The most significant slopes on the test line are found around the bridge over the Van Starkenborgh canal.

- Westbound at km 9, acceleration from Zuidhorn takes place over the bridge (first figure in section 1c). The upward slope hardly leaves any acceleration left. The downward slope returns the height energy to the train and at km 10 the original curve is resumed.
- Eastbound just after km 16, all speed lines bend down uphill (second figure in section 1c). Right afterwards, the thick bundle of trains at almost 120 km/h start braking into Zuidhorn. Slower trains keep coasting downhill, seeing speed rise again before decelerating to stopping. Note that trackwork has removed the 100 km/h speed limit between the bridge and Groningen, which used to be challenging for ATO in the earlier phase 2.

3 Journey Profile updated during run

3a Track changed in JP during run

Not many tests were carried out on track changes. One relevant case has been found in run D4-06 on 25-7-2021:

- JP from Grijpskerk to Zuidhorn originally leads to SP 111 (the unusual “left” platform track 2).
- A couple of hours in advance, this is “corrected” to 122 (common eastbound platform track 1).
- 20 minutes before operations the SP is changed to 111 again, perhaps to re-enable the test.
- Finally the SP is changed to 122 only 5 minutes in advance, probably in order to find out if ATO can cope with this.
- ATO does not seem to handle this well. At 3:21:29 the train occupies the first block section unique to SP 122 and at 3:21:43 ATO starts DISENGAGING.

Buitenpost track 1 is visited only once under ATO: C1-01 returning as C1-02. This track use was included in the original JP for these runs so in that sense not a track change.

3b Passing time changes during run

The table below gives the time changes found in JP data. Not all are exactly equal to one of four scenario’s in the test plan, so the closest scenario is mentioned.

Ride	Date	JP updated	Time in advance	Latest Arrival old	Latest Arrival new		Window old	Window new	Closest scenario	Driving profile	Actual passage	JP new met?
D3-08	24-07	4:16:26	3'	4:19:16	4:24:16	(+5')	120	0	3b1	ATO off		
D4-06	25-07	3:18:48	10'	3:29:18	3:34:18	(+5')	120	120	3b4	ATO off		
D4-08	25-07	3:35:23	10'	4:42:18	4:47:18	(+5')	120	0	3b2	Zh-Hdp steady 50 km/h	4:47:14	almost
D5-02	26-07	0:52:06	5'	0:57:19	1:02:19	(+5')	30	120	3b4	0:52:38 start coasting	0:57:12	no
D5-04	26-07	2:13:00	2'	2:14:49	2:19:49	(+5')	30	120	3b3	2:13:35 start "coasting"	2:18:34	yes
D5-06	26-07	3:27:57	2'	3:29:19	3:34:19	(+5')	120	120	3b3	3:28:34 brake, then coast	3:33:04	yes
E4-04	02-08	2:11:06	3'	2:14:55	2:19:55	(+5')	30	30	3b1	2:12:03 coast	2:14:48	no
E4-06	02-08	3:25:44	3'	3:29:25	3:34:25	(+5')	30	30	3b1	3:27:07 brake, steady 35 km/h	3:34:14	yes
F1-06	05-08	3:26:12	3'	3:29:28	3:34:28	(+5')	30	30	3b1	3:26:27 brake, steady 30 km/h	3:34:26	yes

Successful driving strategies are, depending on the timeliness of JP update:

- **Early notification:** cruise at a lower speed (D4-08). Although a window of 0 seconds is virtually impossible to meet, this case is well done within controlling and measuring tolerance.
- **Late notification:** first brake when necessary (D5-06 followed by coasting, E4-06 and F1-06 followed by steady). This way, TP passage is achieved within the arrival window.

Upon late JP update notification, coasting may not be sufficient to meet a postponed arrival window (D5-02 and E4-04). Note that after JP update, it takes some 35 seconds for ATO to carry out an intervention, whereas E4-04 and E4-06 need a minute.

Two other JP updates are worth mentioning.

- D5-06: Grijpskerk and Zuidhorn were changed from STOP to PASS more than 10 minutes in advance, but the train has made both stops anyway.
- D5-04 was changed from PASS to STOP at Zuidhorn. The train passes the platform but makes a stop 500m beyond the regular stopping position. This happens at release speed, MA being extended.

4 Unplanned stop and hindrance from other train

Late clearance of signals can be detected automatically. For this research question, late route setting after a planned stop is not relevant. The analysis focuses on test weekends D-F. Apart from a situation in Zuidhorn without ATO, all cases took place around signal 412 at Hoogkerk Aansluiting.

The column ‘Signal desired’ indicates when the train is about to face a yellow signal, but this is no strict mathematics.

Run	Signal	Cause (+delay)	Signal desired	Signal open	Remarks
D2-02	ZH$384	revoked_gsmr	22-7-21 04:10:23	4:12:08	ATO off
D4-02	HGKA$412	train ^ 37487	25-7-21 00:56:10	0:58:03	ATO brakes from 70 to 9 km/h, at beacon acc. to 41 km/h and brake to stopping (all ATO)
D5-02	HGKA$412	rijweg_PPR	26-7-21 00:56:38	1:00:22	0:58:04 ATO brakes to 9 km/h, 0:58:56 ATO off. Manual stopping 0:59:00 and last part to Hgka.
E1-02	HGKA$412	train ^ 37487	30-7-21 00:56:24	0:58:18	0:56:54 ATO brakes from 98 to 9 km/h, at beacon acc. to 43 km/h and brake to stopping.
E2-02	HGKA$412	train ^ 37487	31-7-21 00:56:20	0:57:50	0:56:57 ATO brakes from 89 to 9 km/h, at beacon acc. to 43 km/h and brake to stopping.
E3-02	HGKA$412	train ^ 37487 +1	1-8-21 00:56:19	0:58:31	0:57:00 ATO brakes to 9 km/h, 0:58:30 ATO off, manual stopping 0:58:39. Departure by ATO.
E4-02	HGKA$412	train ^ 37487	2-8-21 00:56:22	0:57:24	0:57:04 ATO brakes -0,4 m/s², upon 0:57:36 MA extension (no loop) “braking” at -0,02 m/s², end brake -0,4 m/s² towards arrival 0:59:06
F1-02	HGKA$412	train ^ 37487	5-8-21 00:56:11	0:57:40	0:56:12 ATO aborted, manual braking from full speed to stopping.
F2-02	HGKA$412	train ^ 37487	6-8-21 00:55:31	0:57:51	0:56:01 ATO starts braking at -0,4 m/s², 0:56:18 at 76 km/h ATO aborted, manual braking -1,4 m/s²
F3-02	HGKA$412	train ^ 37487 +3	7-8-21 00:56:10	1:01:21	ATO off

Various situations occur:

- According to D4-02, E1-02, E2-02 and E4-02, *ATO can handle an unexpected braking curve* and reacts with appropriate driving behaviour. Note that in these cases the MA is extended before the train reaches the red signal (and would need to stop).
- E3-02 and D5-02, however, reach the red signal under release speed. ATO smoothly brakes until 0:58:23 but at 0:58:30 driving state changes to steady. When the ATO train is only 17 m before the red signal and still does not start final braking, the driver stops the train. From the available data it is uncertain if ATO would have done so within the short remaining distance.
- In F1-02 and F2-02 the driver decides in an early stage not to rely on ATO braking adequately and intervenes by *manual braking*.

Interesting side finding: sometimes, the ATO driving state does not match with train behaviour:

- In approach of red signal HGKA$412, D4-02 runs in driving state STEADY while speed slowly falls from 76 to 72 km/h. In general this run shows “nervous” driving state changes, while the speed profile runs quite smoothly.
- D5-02 “accelerates” from 64 to 54 km/h.
- D5-04 runs “steady” but speed is falling from 75 to 63 km/h.
- E4-02 is “braking” with a tiny deceleration rate rather seen while coasting.

5 Deviating Segment Profile: TSR

On the stretch Grijpskerk-Buitenpost, several runs received a Temporary Speed Restriction (6th Segment Profile (ID 218), 2nd Timing Point (ID 19)). The TSR was communicated to the train by means of the SP, but not included in the ATBNG. The table below gives the relevant runs as far as operated under ATO. Start and End Location were recorded in cm but here given in meters.

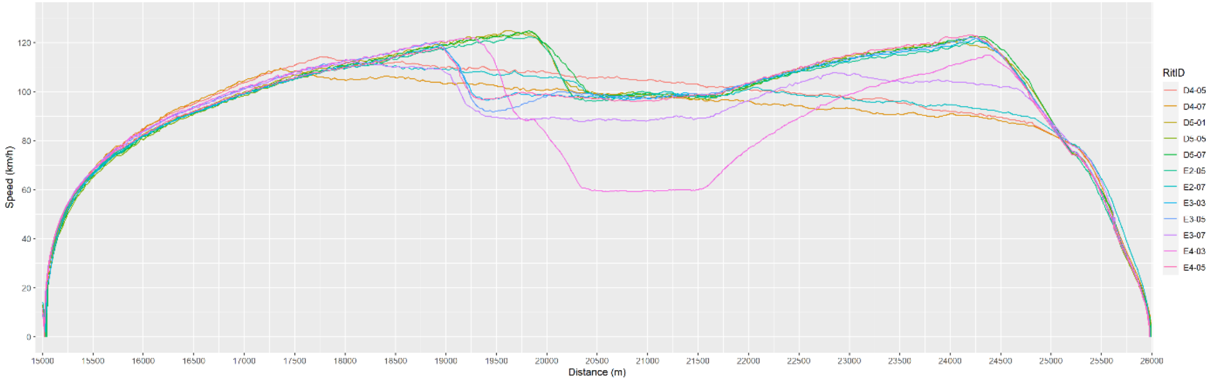
RitID	TracksideLogEntry Date&Time	Start Location	End Location	Allowed Speed	Operated Speed*	Speed profile
D4-05	2021-07-25 02:25:11	7095	8100	110	104	already coasting <110
D4-07	2021-07-25 03:37:59	7095	8100	110	97	already coasting <110
D5-01	2021-07-26 00:01:44	7095	8100	100	98	brake, steady 100, accelerate
D5-05	2021-07-26 02:45:30	7095	8100	100	99	brake, steady 100, accelerate
D5-07	2021-07-26 04:01:26	7095	8100	100	99	brake, steady 100, accelerate
E2-05	2021-07-31 02:46:10	7095	8100	100	99	"overbrake", 100, accelerate
E2-07	2021-07-31 04:00:53	7095	8100	100	98	brake, steady 100, accelerate
E3-03	2021-08-01 01:34:23	6095	8100	100	97	brake, steady 100, accelerate

E3-05	2021-08-01 02:46:10	6095	8100	100	97	"overbrake", 100, accelerate
E3-07	2021-08-01 04:01:06	6095	8100	90	88	brake, steady 90, accelerate
E4-03	2021-08-02 01:34:11	7095	8100	60	59	brake, steady 60, accelerate
E4-05	2021-08-02 02:46:07	6095	8100	100	96	brake, steady 100, accelerate

*measured at beacon **7396**

All restrictions with subtle differences in start location and allowed speed are well respected by ATO. At the start location, most runs tend to finish braking slightly late, leading to an unnecessarily low speed and some re-acceleration. This particularly holds for E2-05 and E3-05. Speed profiles of runs with TSR are shown in the graph below.

All eastbound test runs with speed reduction



11 Driving profiles (fast vs. energy efficient)

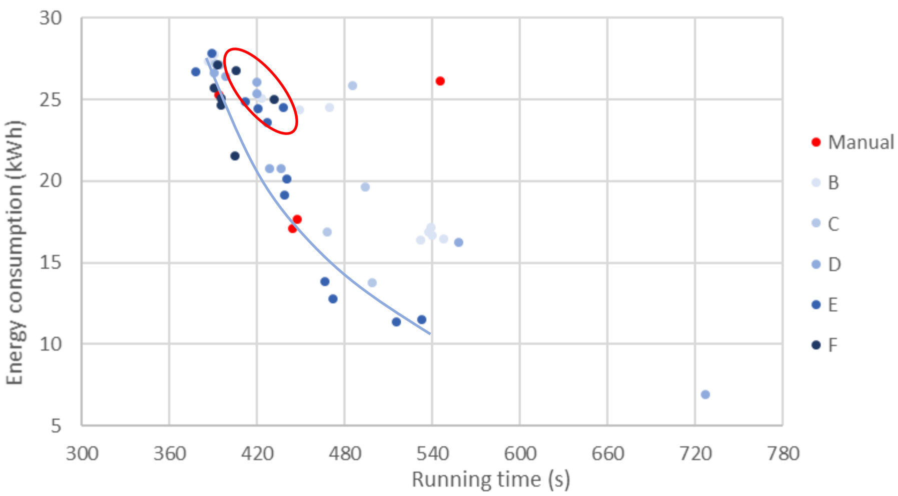
The test plan starts with a research question about the current operational timetable. The current timetable on this specific line does not contain much slack so this would be close to shortest running time. Moreover, scheduled running times in JPs only coincidentally equalled the current timetable, and Hoogkerk is not a regular stop. Hence, the topic is addressed slightly differently with the same intentions.

During the tests, ATO has not permanently been turned on. In 423 stop-stop runs where energy data is available:

- 340x ATO is 100% engaged.
- 25x ATO is engaged 91-99%; these first two categories are included in the ATO analyses.
- 7x ATO is engaged 60-85% of the time; these are left out.
- 20x ATO is completely off. These are plotted as manual reference, but the number is too small to serve as a control group for calculation.

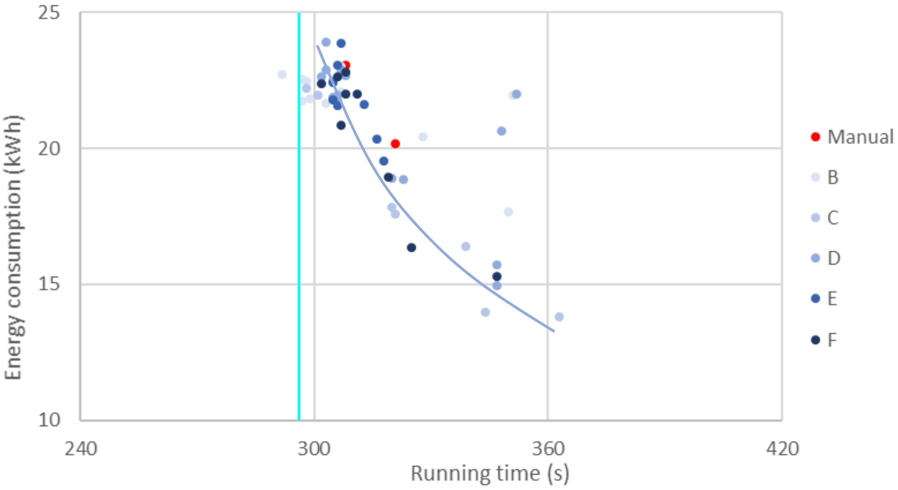
The test programme covers 6 stretches from stop to stop. For each, energy consumption is plotted over running time. Energy is calculated by multiplying torque and engine speed. Every stretch has a shortest running time given the rolling stock characteristics, top left in the graph. Energy saving is possible by coasting (cruising at lower speed is another saving strategy, but this is rarely applied in Phase 2B), resulting in longer running times. The curve is bent: a short coasting distance already yields substantial savings and takes few running time. Further coasting brings increasing “slowness”. An indicative trendline is drawn blue in each graph.

Hgka-Zh (westbound)

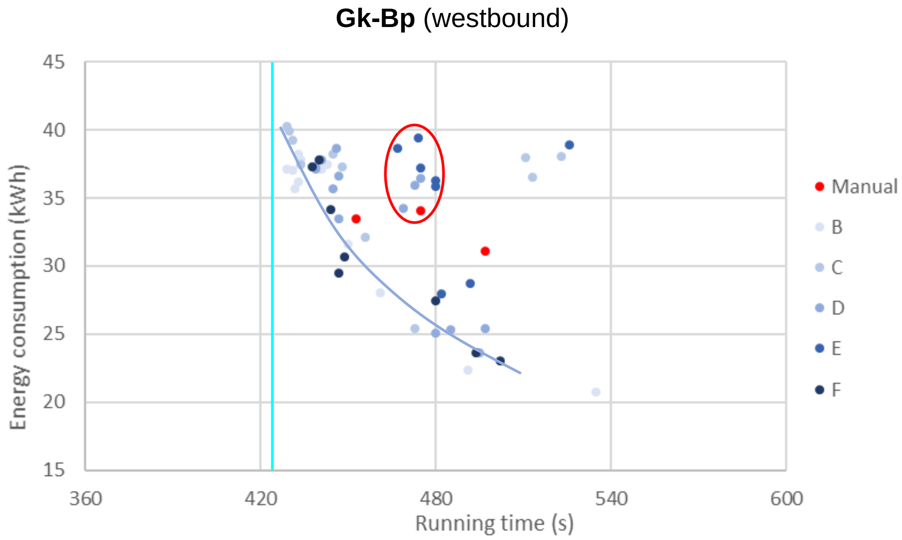


Most runs in later weekends (dark dots) show a clear trade-off between running time and energy consumption. The red circled cloud relates to a couple of runs first coasting 1.5 km at 50-70 km/h and then accelerating to full speed. This seems to aim at the Hoendiep passing TP but results in a relatively high combination of energy consumption and running time.

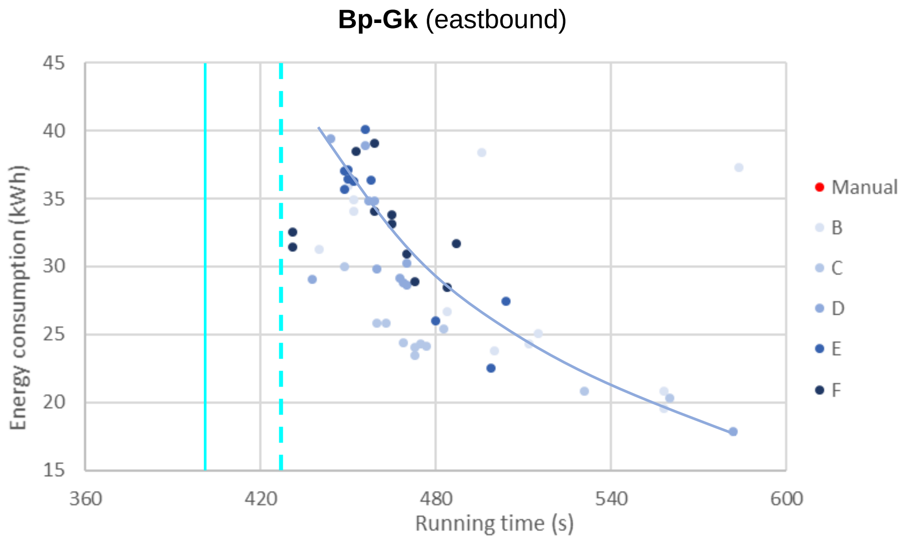
Zh-Gk (westbound)



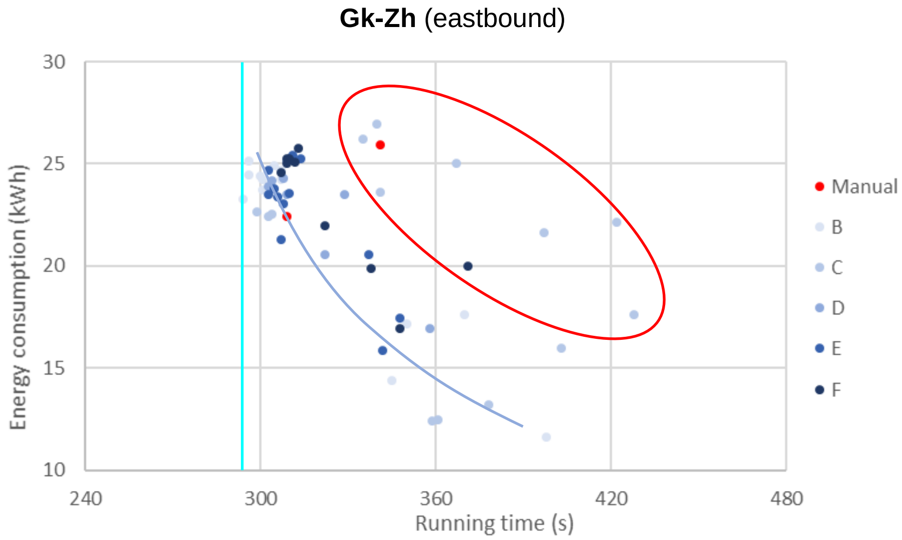
This stretch shows optimal driving in weekends E and F. Two manual runs perform on the worse boundary of the "main cloud". Part of the early tests (light dots) run less efficient. The left outlying run C1-03 started at a wrong (further) position, which explains a shorter running time than others. The vertical blue line is clarified at the end of this paragraph.



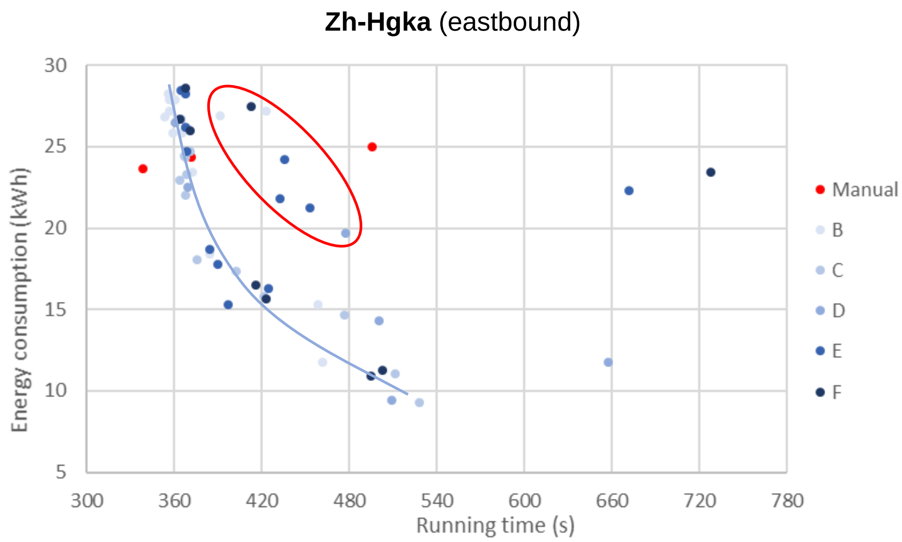
Remarkable in this graph are a couple of runs in D5 and the E weekend (red circled): a TSR (see section 5) made these runs both slow and energy-consuming. Typically, these runs first accelerated to approx. 120 km/h, then run a certain distance steady at mostly 100 km/h and before the next stop accelerated again.



Interesting on the first eastbound stretch is departure speed: most runs start under release speed. No ATB loop is installed along platform 2 in this unusual driving direction and the train has to pick up MA at beacon 7313. However, F1-02 & F3-02 (two dots at 431s left in de graph) accelerate continuously right away, touch 40 km/h around the beacon and accelerate on. This could happen because of ATBNG connection loss, which also caused stopping not far enough at the next station Grijpskerk. The point-related 80 km/h limit works out as not restrictive, so these trains make un unperturbed acceleration to line speed and make too few meters. Still, regular trains (the bright blue line) are faster.



In early weekends, tests have been done with additional timing points at level crossings in-between. These were less successful, resulting in the spread light dots. The dark dot within the red circle is F3-06, which braked to fiercely before the (permanent) speed limit change from 120 to 100 km/h, ending up at 87 km/h and re-accelerating again.



Zh-Hgka shows a wide variation in efficiency:

- Many trains run an optimal curve (blue) by accelerating and less or more coasting.
- Quite a few trains run full speed, brake too fiercely towards the permanent 100 km/h limit, then re-accelerate before finally decelerating to stopping (red circled).
- A few runs (E4-06 & F1-06 e.g. top right in the graph) conduct a JP update experiment (see section 3b). They first accelerate to over 100 km/h, then cruise for an extended distance at only 30 km/h and finally run 80 km/h shortly before stopping. This raises both running time and energy consumption, but given circumstances it may still be more efficient than making an unplanned stop – although 30 km/h is extreme.

Running times by ATO versus regular operation

Judging fast running times is possible by comparison with daytime operational practice. To this end, the median of train GTW2/8 in series 37400 over September & October 2021 is plotted with a bright blue line (energy consumption not available). This is not possible for runs to and from Hoogkerk Aansluiting, not being a regular service stop.

On Buitenpost-Grijpskerk, regular eastbound trains depart unperturbed from track 1, while ATO faces release speed. Operational running time can be corrected for this. Most test runs hold 13 km/h over 100 m, taking 28 s. Without limitations, the acceleration shifts forward and the same distance is covered at 140 km/h in 3 s, so time difference is 25 s. The fictive operational running time with departure at release speed is drawn as dotted line.

Although the median does not even reflect the fastest operational runs, this running time seems hard to beat for ATO. That also holds for the next three graphs were the comparison is possible. This is remarkable, since the earlier Phase 2 indicated that ATO could outperform manual operations. A closer look shows possible explanations in all stages of the speed profile:

- **Acceleration.** According to the traction characteristics of GTW3 in DONNA (recently calibrated with operational data) accelerating from 0 to 140 km/h takes 5.8 km. The graphs with all ATO runs in item 1c show that two runs perform like that: D4-04 & 08 eastbound from Buitenpost (first stretch). All other test runs achieving 140 km/h (both west- and eastbound) need 7.5 km. Seemingly, a slightly reduced level of engine power has been available or chosen in most test runs.
- **Cruising.** ATO usually keeps speed more or less constant close to the allowed limit, except two eastbound parts. On second stretch Grijpskerk-Zuidhorn speed slightly falls despite driving state STEADY and on the last part Zuidhorn-Hoogkerk the speed limit drop from 120 to 100 km/h is inefficiently handled.
- **Deceleration.** From operational analyses is known that drivers widely apply braking rates up to 0.5 m/s². ATO may be expected to brake later and stronger. Data show, however, that considering all records in driving state DECELERATION only 7% exceeds 0.5 m/s². In the earlier ATO phase 2 a higher braking rate was used but the resulting speed profile was not smooth. This seemed to be tackled by setting a lower deceleration rate.

Meeting the expected ATO benefits requires attention to these causes.

12 Shorten of MA by revoking of signal

One case of revoking has been found (upper line in table under 4a) but the train did not run under ATO at the time.

2.3 Summary

The table below shows the summary of the results presented in section 2.2

No.	Research item	Conclusion	Passed?
1a1-2	Stopping position	At EoA ATO consistently stops within a few meters from the specified position. Not near EoA, part of test runs stops too far.	±
1a3	Departure after planned stop	With ATBNG loop or early MA, ATO accelerates continuously. When relevant, ATO respects an initial release speed.	+
1b	Accurate driving	The wider the JP window, the more trains in it. Quite a few runs arrive earlier than the window, although there is no minimum speed. Most but not all late arrivals are the effect of JP tests such as handling a TSR.	±
1c	Fixed speed restriction	Regular line speeds are well respected, but a speed descent from 120 to 100 km/h is not handled properly	±
3a	Track changed	This test case was sufficiently tested during phase 2.Only one case was observed during phase 2B and indicates that ATO has problems in obeying a very late track change.	-
3b	Passing time changes during run	With early notification, ATO meets the new passing time. With late notification, both effective and ineffective ATO behaviour has been observed.	±
4	Unplanned stop and hindrance	ATO can follow an unexpected braking curve, but the ability to make a full stop under release speed has not been observed.	±
5	TSR	Various restrictions are well respected by ATO. The lower speed section is sometimes entered by braking too much.	±
11	Driving profiles (fast vs. energy efficient)	The trade-off between fast driving and energy saving is clearly visible. Unfortunately, fastest running times are longer than regular manual operations. Energy savings cannot be determined because there are no similar data on manual operations.	±

+ Passed completely
± Partially passed, we observed good and bad results
- Did not pass

2.4 Additional observations during phase 2B

Besides the results there are a few observations that we have to add/address to put the results in context.

2.4.1 Non-delayed braking

Part of the test scope was getting an understanding between delayed braking and non-delayed braking. Currently train drivers are required to start braking as soon as they pass a restrictive signal under ATBNG, although it might not be necessary regarding the braking characteristics of the train. In the project we call this “non-delayed braking”. The ATBNG systems allows the option for delayed braking, postponing the starting point for braking depending on the distance towards the limitation and the braking characteristics of the train.

During the tests it was observed that in many cases where delayed braking might be of an influence, the signalling layout and the distance between signals is already highly optimized for the timetable. That combined with the fact that the ATO-system was configured with a subtle braking style made that the train started braking before the restrictive signal. Therefore it was not possible to gather data towards the reduction in running time between delayed and non-delayed braking.

2.4.2 Implementation of ATO functions

The implementation of a few ATO functionalities was different than expected. The interface for the train driver was not showing the right arrival times nor the next braking indication. Making it difficult for the driver to anticipate the next action of the ATO-system.
Also the parameter “arrival window” used to create a time window for passing a timing point (instead of a fixed timeslot) was not implemented according to the expectations that were based on the SUBSET-126.
Lastly, cruising and coasting was difficult to achieve in the combination of TCMS and ATO-system. So to implement those functions a number of tricks were created that might have influenced the energy usage of the train in a negative way.

2.4.3 Missing time synchronisation

There was no time synchronisation between the ATO systems, the different systems on the train, and local GMT. Also the time difference between these systems was not stable between the test shifts. Some systems added an additional offset of +/- 3 seconds per day. Unfortunately during the execution of the tests, these offsets were not taken into account. This made it difficult to properly access the punctuality of ATO during the test runs. After the test campaign this has led to an additional step for analysing the tests (see 2.1.1).

2.4.4 Positioning

The ATO system heavily depended on the location of ATBNG beacons for positioning. This had the disadvantage that the given positions of the beacons had to be accurate and that all beacons had to be read correctly. Both could not be guaranteed which has led to stopping positions being inaccurate.

2.4.5 Engine power

The tests have been conducted with a 15 year old passenger train. This trainset was the same trainset that was used during the previous phases. During the phase 2B tests it happened a few times that one of the two engines would temporarily shut down, leaving only one engine available for acceleration. Also feedback was given back from the test crew that the acceleration of this trainset in general was less than some other trainsets and compared to 15 years ago. This has influenced the accuracy and energy usage of the train in a negative way.

3 An overview of the main conclusions and recommendations

Before going in depth into the conclusions we have to note that this test was conducted with a single solution (prototype), which was calibrated and improved in the first periods of the test campaign. The following conclusions are telling us something about this solution, but they can not necessarily be applied to the ATO concept as a whole (both negative as positive results).

The test was conducted on a line with a class B automatic train protection system (ATBNG). This system does not have an interface specification between the ATO system and the ATP system. Relying on information from that system for signalling information and positioning has proven to be difficult.

The ATO system used for phase was different then the version used for phase 2 and completely relied on ATBNG data for positioning and signal aspects. During the previous phases positioning was determined by GPS combined with the odometer.it 2B Therefore it is not possible to compare the results of these two phases directly but we can compare the different systems.

3.1 Conclusions

The phase 2B tests were focused on advanced ATO functionality being: accurate stopping both from a timing perspective and a location perspective (testcase 1), dealing with updates in the timetable during the run (testcase 3), coping with operational hinderances (testcase 4), dealing with updates of the segment profile (testcase 5), and driving using different profiles to find the trade-off between timing and energy optimisation (testcase 11).

The tested solution is capable of executing these advanced functionalities (testcases 1,3, 4 and 5). The test train was able to halt at the stopping location (+/- 3 meters) and at the right time. Updates were correctly incorporated into the speed profile when send in advance and within reasonable limits. This applies for timetable updates, track changes and segment profile updates. Also a clear drop in energy usage was observed between the different ATO driving modes, driving full speed and driving with an economic driving style combined with higher buffers (testcase 11).

All advanced functionalities have been witnessed and seen working. But the results have not been consistent. Which was expected due to the fact that we are dealing with a prototype. The positioning system relied heavily on the ATBNG, and sometimes the connection between ATO and ATBNG was lost. Also optimisation is still possible in the way certain functions (like arrival window, cruising/coasting) are implemented and executed.
Compared to the phase 2 tests we were able to gather more data and executed test runs driving according to a timetable with an energy reduction in high buffer timetables.
Overall we can conclude that this ATO system proved to have the potential to execute basic and advanced functionality under ATBNG but also that it was difficult to tune the ATO-system with the ATBNG-system which resulted in signalling information and positioning sometimes being processed incorrectly. In addition to the 'technical' integration of the ATBNG and ATO unit, a safety analysis is required whether the combination of ATBNG with ATO has a sufficient level of safety, both operationally and technically.
ATO over this (advanced) class B system requires a lot of effort and understanding from all parties involved. ATO over ETCS will be much easier to develop and implement as this is an European standard (TSI) where ATBNG is a custom vendor dependant ATP system specifically for The Netherlands. Based on this ATO system, we conclude that a significant development step is still necessary for a stable and reliable ATO-system using information from ATBNG.
Time synchronisation between different subsystems is crucial. This becomes awkwardly clear when the ATO system is running on a different timing than the automatic route setting. This leads to trains consequently arriving too early or too late at the station. We were able to ‘repair’ the time synchronisation during the test runs and for analysis but this was difficult and took a lot of effort.

3.2 Comparison between phase 2B and phase 2

During the phase 2B tests the ATO system was able to drive according to a timetable, cope with changes to the timetable and cope with delays. The ATO system used in phase 2 was not able to this. The addition of this advanced functionality is a huge improvement.

The accuracy for the stopping position at platforms during phase 2B is similar to the last periods of phase 2. A high percentage of trains were able to stop within the margin of +/- 3 meters. Performance without EoA seems to be a little worse on a specific location (Vierverlaten) than achieved during phase 2. The reason is unknown and requires further investigation.

3.3 Recommendations

During the tests of phase 2B we have learned a lot and encountered several topics that are worth mentioning as recommendations for further testing ATO systems:

- Testing on class B systems for the purpose of gathering data for ATO over ETCS is not recommended. The time and effort to develop a realistic interface with a class B system is at the expense of the development of the ATO system.
  Data from this test can only be used for ATO over ATBNG, The performance of ATO systems on specific ATP systems (e.g. ETCS) should be tested on that specific ATP system,
- Testcase for energy usage under ATO should be a separate test over a longer period and a longer track for both intercity and stop services. Ensure there is enough reliable compatible data available from manual driven trains to be able to analyse and compare ATO vs manual,
- Time synchronisation of the different systems is essential for testing and data analysis. Time synchronisation has to be part of the system specification,
- Assign dedicated preparation and optimisation periods before running the testcases so the testcases can be tested with a mature and stable system,
- Ensure to validate functionalities (simulations) before actual testing, to prevent unexpected situations during testing,
- Timetables need to be consistent; use a standard timetable that can be adjusted,
- Use a modern, updated train or a more easy installation, configuration and optimisation,
- ATO over ATBNG has shown to be very complicated and difficult to tune for reliable and consistent results. A decision to continue testing and further developing ATO over ATBNG should be part of the migration strategy. In addition, a safety analysis is required whether the combination of ATBNG with ATO has a sufficient level of safety both operationally and technically.

4 Appendices

Appendix 1: Test periods

Period	Id	From	To
A	A1	Fri 02/Jul/2021 22:00	Sat 03/Jul/2021 7:00
	A2	Sat 03/Jul/2021 22:00	Sun 04/Jul/2021 7:00
	A3	Sun 04/Jul/2021 22:00	Mon 05/Jul/2021 7:00
B	B1	Fri 09/Jul/2021 22:00	Sat 10/Jul/2021 7:00
	B2	Sat 10/Jul/2021 22:00	Sun 11/Jul/2021 7:00
	B3	Sun 11/Jul/2021 22:00	Mon 12/Jul/2021 7:00
C	C1	Fri 16/Jul/2021 22:00	Sat 17/Jul/2021 7:00
	C2	Sat 17/Jul/2021 22:00	Sun 18/Jul/2021 7:00
	C3	Sun 18/Jul/2021 22:00	Mon 19/Jul/2021 7:00
D	D1	Wed 21/Jul/2021 22:00	Thu 22/Jul/2021 7:00
	D2	Thu 22/Jul/2021 22:00	Fri 23/Jul/2021 7:00
	D3	Fri 23/Jul/2021 22:00	Sat 24/Jul/2021 7:00
	D4	Sat 24/Jul/2021 22:00	Sun 25/Jul/2021 7:00
	D5	Sun 25/Jul/2021 22:00	Mon 26/Jul/2021 7:00
E	E1	Thu 29/Jul/2021 22:00	Fri 30/Jul/2021 7:00
	E2	Fri 30/Jul/2021 22:00	Sat 31/Jul/2021 7:00
	E3	Sat 31/Jul/2021 22:00	Sun 01/Aug/2021 7:00
	E4	Sun 01/Aug/2021 22:00	Mon 02/Aug/2021 7:00
F	F1	Wed 04/Aug/2021 22:00	Thu 05/Aug/2021 7:00
	F2	Thu 05/Aug/2021 22:00	Fri 06/Aug/2021 7:00
	F3	Fri 06/Aug/2021 22:00	Sat 07/Aug/2021 7:00

Appendix 2: Overview of test cases

Test case	Out-of-scope	Phase 2	Phase 2B	Goal of test case	Test case setup	Expected test result
1a Normal run with planned stop (accurate stopping)			x			
1a1 Approach of a planned stop at EoA (in front of the red signal)			x	To assess whether ATO can stop accurately at the correct time and location, even when constrained by a braking curve from a red signal approach.	At the planned stop location a TP is implemented and a stop in the timetable and JP is added with the route setting up to the planned stop location.	ATO stops accurately at the designated location and at the designated time.
1a2 Approach of a planned stop not near the EoA			x	To assess whether ATO can stop accurately at the correct time and location without being restricted by a red or yellow signal	At the planned stop location a TP is implemented and a stop in the timetable and JP is added and the route is set at least 2 signals past the planned stop location	ATO stops accurately at the designated location and at the designated time.
1a3 With planned stop at EoA			x			
1a3a Departure after a stop on an ATBNG loop			x	To assess whether ATO can depart correctly when an ATBNG loop is available	Train at standstill on top of an ATBNG loop. After receiving the green signal the driver engages ATO.	ATO continues its journey by accelerating to the desired speed
1a3b Departure after a stop not on an ATBNG loop			x	To assess whether ATO can depart correctly when an ATBNG loop is <u>not</u> available	Train at standstill at a track without an ATBNG loop. After receiving the green signal the driver engages ATO.	ATO continues its journey by accelerating to release speed. After passing the ATBNG beacon with new EoA, the ATO will accelerate to the desired speed
1a3c Departure after a stop not near an EoA			x	To assess whether ATO can depart correctly when it is not near it's EoA	Train at standstill at a track not near EoA (e.g. open line stop). After the dwell time the driver engages ATO. (Test can also be executed at a track without ATBNG beacon when the platform signal was already showing green at least 2 signals in advanced)	ATO continues its journey by accelerating to the desired speed
1b Normal run with short headway (accurate driving)			x			
1b1 short following with time tolerance 0 seconds			x	To see whether trains running on ATO can more precisely follow the given timetable, so trains can run with a shorter interval	At a planned location a TP is implemented. The JP states the required passing time at the TP and the required precision, 0 (very tight tolerance) or 120 seconds (loose tolerance) T_Arrival_Window = 0	ATO passes the TP at the required time within the required precision
1b2 short following with time tolerance 120 seconds			x	To see whether trains running on ATO can more precisely follow the given timetable, so trains can run with a shorter interval	At a planned location a TP is implemented. The JP states the required passing time at the TP and the required precision, 0 (very tight tolerance) or 120 seconds (loose tolerance) T_Arrival_Window = 120	ATO passes the TP at the required time within the required precision
1c Normal run with fixed speed restriction		x	x	To see whether ATO complies with a fixed speed restrictions	The test is planned at a location with a fixed speed restriction, with the route set and the JP designed in a way that at the start of the test	The ATO train runs near the maximum allowed speed at the start of the test scenario. At sufficient distance ATO decelerates and

						scenario the train is required to run faster than the speed restriction which is at the end of the test scenario	reaches the allowed speed of the speed restriction just before the start of the speed restriction.
1d	Normal run with switch related speed restriction		x	x	To see whether ATO complies with a switch related speed restriction	The test is planned a at switch in the diverting position which has a speed restriction, with the route set and the JP designed in a way that at the start of the test scenario the train is required to run faster than the speed restriction at the switch	The ATO train runs near the maximum allowed speed at the start of the test scenario. At sufficient distance ATO decelerates and reaches the allowed speed of the switch just before the start of the switch
1e	Normal run with slope		x	x			
	1e1 Prevent running at too low speeds at slopes		x	x	To observe that ATO adheres to the allowed speeds at slopes and how the ATO system copes with slopes in an efficient manner	No specific setup will be made. Dedicated runs without stops scheduled for Zuidhorn will be made to analyse the ATO behaviour.	ATO system copes with slopes in an efficient manner
3a	Track changes		x	x			
	3a1 Track changed in JP during run		x	x	To see whether ATO can cope with planned track changes during a run	The test is planned at a location where multiple routes are possible. The route is set through route B and the JP states that the train will run through route A	The train runs according to the JP. At the set time in advance the train receives the route update and adjusts accordingly. The train runs according to the JP through route B
	3a2 Track changed, but not in JP. Track in JP is different from track actually driven			x	To see whether ATO can cope with unplanned track changes during a run	To see the reaction when ATO encounters a different route than in the JP	ATO recognized the change in track and disengages.
3b	Passing time changes during run			x	To see how ATO copes when the passing times in the JP are updated during the run	The test is planned at a TP location. The route is set and the JP has a passing time stated to the TP.	The ATO runs according to JP and after receiving the JP update adjusts driving accordingly to adhere to the new JP. Which probably will included braking to avoid overshooting the TP too early.
4a	unexpected red signal			x	To assess whether ATO can cope with an unexpected red signal	At a planned location the route setting ends, but in the JP no stop is planned.	ATO runs the train and tries to adhere to the JP, but when ATO encounters the unexpected red signal it will stop before the red signal.
4b	Hindrance from other train			x			
	4b1 Crossing train in front delayed, JP not updated			x	To see how the ATO system adapts to hindrance from delayed trains in front of it	At a planned location the route setting is delayed compared to the usual route setting for the used timetable. The JP still reflects the usual timetable	ATO runs the train according to JP, encounters the delayed route setting and adheres to any braking curve resulting from it, when the route is extended the train speeds up again and tries to make up for lost time
	4b2 Train in front delayed. JP updated			x	To assess how ATO copes with a delayed train in front of it when the JP is updated to reflect this.	Multiple blocks of route setting are delayed step by step to simulate a slow train directly in front of the ATO train. The delayed route setting is calculated in advance to simulate a train running for example at 80 km/h, and executed by the train dispatcher manually. The test starts with a JP for a normal run to the train, but a set amount of time in advance the ATO-OB receives an updated JP to reflect the delayed route setting. The	The ATO train runs according to the JP and receives a JP update, ATO tries to adhere to the new JP thereby avoiding any direct hindrance from the delayed route setting in the form of yellow of red signal approaches.

						updated JP is created in advance of the test and sent to the train at the designated time.	
4b3	Train in front delayed. JP not updated			x	To assess how ATO copes with a delayed train in front of it when the JP is not updated	Multiple blocks of route setting are delayed step by step to simulate a slow train directly in front of the ATO train. The delayed route setting is calculated in advance to simulate a train running for example at 80 km/h, and executed by the train dispatcher manually. The	The train runs according to the JP, but encounters yellow or red signals because of the delayed route setting. Unaware of the fact that multiple blocks have a delayed route setting, whenever a signal turns green, ATO tries to run as fast as allowed by the safety system to make up for lost time. This creates a very uneven run where the train speeds up and has to brake a lot.
5a	TSR in ATBNG			x			
5a1	TSR *(not)* incorporated in SP			x	To see whether ATO can cope with a TSR incorporated in ATBNG and ATO.	Two possible setups are possible: 1. At a chosen location a TSR is incorporated in ATBNG. the JP and SP are not updated to reflect this 2. A location with a permanent speed restriction is used. The SP uses a higher than allowed speed at this location and for the JP this higher speed is used in the TP times.	The train runs according to JP and encounters the TSR. ATO adheres to the safety envelope of ATBNG and tries to make up for lost time
5a2	TSR not *(not)* incorporated in SP			x	To see whether ATO can cope with a TSR incorporated in ATBNG but not in ATO.	Two possible setups are possible: 1. At a chosen location a TSR is incorporated in ATBNG and the SP. The JP is not updated to reflect this 2. A location with a permanent speed restriction is used. The SP incorporates this TSR, but in the JP a higher speed is used in the TP times.	The train runs according to JP and encounters the TSR. ATO adheres to the SP and tries to make up for lost time
11a	Current operational timetable, as energy efficient as possible			x	To assess how punctual and energy efficient ATO can run	The timetable and route setting are identical to the current commercial timetable. The JP uses this timetable	The train runs in a punctual and energy efficient manner
11b	As fast as possible, this scenario can be performed without and with delayed braking to show differences in train travel times		x	x	To see what the fastest possible travel time is without ATBNG delayed braking	The route is set such that the train encounters the usual red signals as during commercial service, and thus the train is stopping at the normal commercial stops for a realistic time.	The train runs as fast as possible, while still stopping at the normal commercial stops for a realistic time.
11c	Intermediate timetable between 11a and 11b, as efficient as possible			x	To see whether ATO can run punctual and energy efficient with a faster timetable	The timetable and route setting are according to a schedule in between the current commercial timetable and the fastest possible travel time. The JP uses this timetable	The train runs according to the JP, but uses more energy and has more delays compared to 11a
12	Shorten of MA by revoking of signal			x	To see whether ATO correctly handles shortening of MA within ATBNG and stops the train at the correct position (directly in front of the red signal).	The route is set initially such that the train encounters only green signals	Train stops at the correct position in front of the revoked signal. Resuming may only be initiated by the driver.

Appendix 3: Summary

What is ATO?

ATO is a technology that enables automated driving on the railways. The tested ATO system supports the train driver and takes over tasks. In an ATO system, depending on the level of automation, the actions performed by the train driver can be partially or fully automated. In this exploration, the second level of automation was tested (GoA2). This means that the system controls the brakes and traction. The driver and conductor continue to perform the other tasks. This level of automation is similar to the autopilot in an airplane.
An ATO system consists of a system in the train (ATO-OnBoard) and a system that is linked to traffic control (ATO TrackSide). The ATO-OnBoard is integrated into the train and retrieves data from the on-board computer and/or OnBoard of the (ERTMS-ETCS/ATB) train control system (such as location, speed, driving permission). Based on this data, the ATO-OnBoard can calculate the ideal speed, braking and acceleration curve and send traction and brake commands.

ATO has the potential to use rail capacity more efficiently. By driving more accurately, the spread in the execution of the train service is reduced. This creates more space on the track so that trains can run closer together with a higher punctuality. Local bottlenecks can be solved and the track can therefore handle more trains at the same time. Energy can also be reduced with ATO because it is possible to optimally adjust acceleration, speed and brakes. In addition, ATO offers opportunities to further improve the reliability and safety of rail transport.

Tests in Groningen

In the spring of 2019, ProRail, the province of Groningen, carrier Arriva Nederland and train manufacturer Stadler carried out the first tests with ATO (phase 1). During these tests, the driver was still responsible for the safety on the train. The tests took place on the Groningen - Zuidhorn railway line, under the ATBNG train influence system. ATBNG stands for "Automatic Train Influencing New Generation" a train influence system that helps drivers avoid missing railway signals.

After this first successful trial, follow-up tests were carried out at the end of 2019 and the beginning of 2020 (phase 2). The first test runs with passengers in an automatically controlled train have taken place in practice, in order to be able to examine the passengers experience. These tests took place on the Groningen – Buitenpost railway line.

As a result of these tests, there was a need for additional answers to specific functionalities of ATO.

In the summer of 2021, ATO trials were again carried out by the above mentioned parties, to test additional specific functionalities of ATO (phase 2b). These tests consisted of a number of components:

1. Driving according to a timetable, which can also change while driving. In order to investigate how ATO deals with delays or changes during the ride.
2. Testing with stopping at the right position along the platform
3. Driving according to an energy-efficient profile; to see if the use of ATO leads to energy savings. The idea is that ATO drives more evenly and consistently.

How accurately the train can stop (in time and position) depends to a large extent on how well the ATO system knows where it is at that moment, the positioning. During the previous tests, GPS was mainly used to determine the starting point of the journey, then the number of revolutions of the axles of the train was measured to determine where the train was. During the tests in 2021 (phase 2b), information beacons in the tracks were also used. By feeding the ATO system with information from the location of information beacons, the system can determine the position where the train is with more accuracy. This is similar to the positioning of the ERTMS train protection system.

ERTMS is a new, European, train protection system that will eventually become the new standard for railways.

Below are the results of the 2021 trial for each component.

Driving according to a timetable and changes to it
During the trial, an attempt was made to drive according to a pre-set timetable, with the possibility of being able to change it while driving. This is to see if the ATO system can deal with changes that may occur in a normal timetable. As an example, one can think of a train that is behind the timetable due to an unforeseen delay, therefore has to wait a while for an oncoming train and tries to make up for the delay incurred.

The changes in the timetable were correctly processed by the train. The train adjusted its speed accordingly, provided that these changes were not communicated to the ATO system too short in advance. The system needs enough time to process a major change otherwise the change cannot be implemented in time.

Result:
The test has shown that the ATO system can run according to a timetable. Changes to the timetable while running, track route changes and changes to track characteristics (such as maximum speed) are also correctly processed by the system.

Testing at stopping at the right position alongside the platform
At the moment, signs and signals along the track indicate where the train should stop, so that it stops in the correct position alongside the platform. ATO should automatically be able to know where to stop and ATO also knows exactly how the train can brake optimally. In theory, this means later braking and stopping more precisely. This translates into shorter stopping time and shorter travel time.
The test train was tested to see if it could be brought to a standstill at the right position and at the right time by feeding this information into the ATO system. And then to drive a lot of trips and to instruct the train to always stop at the same position.

Result:
The test results showed that with a bandwidth of +/- 3 meters, the train could stop at the requested position alongside the platform and at the right time. This result is within the set margins and meets expectations.

Driving according to an energy-efficient profile
With an airplane or in the car, a cruise control ensures that driving is more economical. This has to do with a more constant speed of the vehicle. In theory, this is also the case with a train equipped with ATO. In addition, the ATO system knows very accurately what the track looks like, but also the stopping time and what time the appearance should be on the platform. This makes it clear to the system whether more or less should be driven at maximum speed.

Result:
During the trial, the degree of energy savings was examined. Unfortunately, there is currently no statement to be made about how much energy an ATO train saves compared to the current daily operation. However, a decrease in energy consumption has been observed between the various ATO settings tested: driving at full speed and driving with an economical driving style. The more time the train gets to run from A to B, the more economical the ATO system does.

The fact that no statement can yet be made about the difference in energy consumption has several reasons.
1. There was no good time synchronization of the ATO system with reality, so the commands given by the system were interpreted differently than expected.
2. The function for passing points where there is no need to stop (such as bridges and switches) was not implemented correctly.

3. The ATO system braked less aggressively than during the previous phases. The ATO system braked earlier to stand still on time, so there was less time left to save energy.

Note: More information on the current energy consumption is needed to make a good comparison with the consumption under this ATO system.

Overall conclusion & recommendations

Overall conclusion: This ATO system has been able to perform the requested functionalities. However, the repeatability left much to be desired and the quantification of the potential was therefore less successful.

Being correctly assured that the train is allowed to start driving and determining the position while driving are important elements of the ATO concept. For both elements, this ATO system depended on information from the current train control system (ATBNG). Interpreting this information proved to be difficult during this test for this supplier.

Based on this ATO system, we conclude that a major development is still needed for ATO over ATBNG. With the arrival of the new train protection system ERTMS on the northern lines, the development of ATO on the northern lines will be easier than under the current system. This is because the integration of information between ATO and ERTMS has already been specified. In order to gain insight into the potential energy savings of ATO, it is advisable to conduct specific follow-up research into this.