Automatic Shunting

ATO driving with obstacle detection system

Verbindt. Verbetert. Verduurzaamt.

The proof of concept and this report has been a partnership between ProRail, Lineas and Alstom.

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Management summary (EN)

ATO Automatic Shunting: Self-Driving Freight Locomotive

Rail freight transport is expected to grow strongly in the coming years, but there is limited infrastructure and a shortage of train drivers. Automatic Train Operation (ATO) is seen as a system leap that can contribute to solving this challenge. ATO can be applied with different levels of automation, from GoA2 as an advanced cruise control to GoA4 as fully automatic transportation.

ProRail, Lineas, and Alstom carried out a Proof of Concept between 2020 and 2022, in which a freight locomotive was fully automated in a non-centrally operated area (NCBG). The locomotive was equipped with an ATO system and an Obstacle Detection System (ODS) consisting of multiple cameras and a radar to detect obstacles. During the tests, there was always a driver on board to intervene in case of unexpected situations.

During the different stages, the ATO and ODS systems were successively exposed to increasingly difficult tasks, with the ultimate goal of driving a fully automatic train. At an event in late November 2022, it was demonstrated that the tested system could drive automatically and even detect obstacles such as people, cars, and wagons in foggy conditions, stopping the locomotive automatically to prevent collisions. Furthermore, it was demonstrated that the systems could detect the position of the switches automatically and that it was possible to drive to a wagon and stop in front of it to couple it.

The results of the entire trial have shown that there are possibilities to operate freight locomotives fully automatically in an NCBG, but there are still challenges. The main findings from the trial are:

- The position of the switches was determined based on the flag, but a driver should check the tongue of the switch. The system tested here could not determine this with sufficient accuracy, especially in more complex situations such as cross switches.
- Obstacle detection "learns" by comparing many images/data. Companies like Tesla have thousands of systems in circulation to collect this data. Within the project, there was only one locomotive available, but it already achieved quite accurate recognition. However, there were limitations such as overhanging grass or low-hanging sun, which made the sensors function sub-optimally. This can be solved by collecting more data. This makes it very labour intensive to scale towards multiple locations as every location and every type of signal needs to be learned.
- Positioning based on GPS provides insufficient accuracy to operate the locomotive. A good safety underlay, such as the current ETCS system with accurate odometry, can provide support in this regard. With more accurate positioning, a wagon can also be coupled without additional intervention by the driver.
- Installing the systems in an existing locomotive requires space. Freight locomotives have a limited amount of the available space because it is already used for the various train systems. Integration of systems and the use of smaller sensors could provide a solution to this.

Overall, the trial was successful. To achieve automatic driving, i.e. on non-centrally operated areas such as Oosterhout Weststad, multiple challenges still need to be overcome. The points mentioned above will need to be addressed first.

A video presentation showcasing the project was created and uploaded to YouTube for public viewing.
https://youtu.be/5m8kTtdJQxY (English subtitles)

Management samenvatting (NL)

ATO Automatisch Rangeren: Zelfrijdende goederenlocomotief

Spoorgoederenvervoer zal naar verwachting de komende jaren sterk groeien, maar er is een beperkte infrastructuur en een tekort aan machinisten. Automatic Train Operation (ATO) wordt gezien als een systeemsprong die kan bijdragen aan de oplossing van deze uitdaging. ATO kan met verschillende niveaus van automatisering worden toegepast, van GoA2 als een geavanceerde cruise control tot GoA4 als volledig automatisch vervoer.

ProRail, Lineas en Alstom hebben tussen 2020 en 2022 een testproject (Proof of Concept, PoC) uitgevoerd waarbij een goederenlocomotief volledig automatisch werd bestuurd in een niet-centraal bediend gebied (NCBG). De locomotief werd uitgerust met een ATO-systeem en een Obstacle Detection System (ODS) bestaande uit meerdere camera's en een radar om obstakels te detecteren. Tijdens de testen was er altijd een machinist aan boord om in te grijpen in het geval van onverwachte situaties.

In de verschillende periodes zijn de ATO- en ODS-systemen achtereenvolgens blootgesteld aan steeds moeilijkere opdrachten met als einddoel een volledig automatisch rijdende trein. Tijdens een evenement eind november 2022 is gedemonstreerd dat het geteste systeem automatisch kon rijden en daarbij zelfs in mistige omstandigheden obstakels zoals mensen, auto’s en wagons kan detecteren en daarbij de locomotief zelfstandig stil kan zetten om botsingen te voorkomen. Verder is gedemonstreerd dat de systemen de stand van de wissels zelfstandig kan detecteren en dat het mogelijk was om naar een wagon te rijden en ervoor te stoppen om de wagon te koppelen.

De resultaten van de hele proef hebben laten zien dat er mogelijkheden zijn om goederenlocomotieven volledig automatisch te laten rijden op een NCBG, maar dat nog genoeg uitdagingen zijn. De belangrijkste bevindingen uit de proef zijn:

- De stand van de wissels werd bepaald aan de hand van het vlaggetje, maar een machinist hoort de tong van het wissel te controleren. Het systeem dat hier werd getest kon dat niet voldoende nauwkeurig bepalen, zeker niet bij complexere situatie zoals kruiswissels.
- Obstakeldetectie “leert” door veel beelden/data te vergelijken. Bedrijven zoals Tesla hebben vele duizenden systemen in omloop om die data te vergaren. Binnen het project was er maar één locomotief beschikbaar, maar daarmee werd al een behoorlijk accurate herkenning gedaan. Wel waren er beperkingen zoals overhangend gras of laaghangende zon, die ervoor zorgde dat de sensoren niet optimaal functioneerden. Dit kan worden opgelost door meer data te verzamelen. Dit maakt het zeer arbeidsintensief om op te schalen naar meerdere locaties, aangezien elke locatie en elk type sein moet worden geleerd.
- Positiebepaling op basis van GPS biedt onvoldoende nauwkeurigheid om de locomotief te kunnen besturen. Een goede veiligheidsonderlegger, zoals het huidige ETCS-systeem met nauwkeurige odometrie, kan hierin ondersteuning bieden. Door een nauwkeurigere positiebepaling kan ook een wagon gekoppeld worden zonder extra ingreep van de machinist.
- Voor het inbouwen van de systemen in een bestaande locomotief is er ruimte nodig. In locomotieven is de beschikbare ruimte beperkt doordat er al deze wordt gebruikt voor de verschillende treinsystemen. Integratie van systemen en het gebruik van kleinere sensoren zou hierin een oplossing kunnen bieden.

Al met al kan worden teruggekeken op een succesvolle proef. Om automatisch rijden, zoals bijvoorbeeld op NCBG zoals Oosterhout Weststad, te kunnen realiseren moeten nog meerdere uitdagingen worden overwonnen. Bovengenoemde punten zullen dan als eerst moeten worden opgelost.

Er is een videopresentatie gemaakt die het project toont en op YouTube is geüpload voor publieke weergave.
https://youtu.be/iKoxbnISuT0 (Nederlandse ondertiteling)

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1 Introduction

1.1 Motivation

For the next decades an increasing demand is expected for rail freight operation. But the infrastructure capacity is limited and the shortage of train drivers is increasing. Automatic Train Operation (ATO) is believed to be one of the pillars that can support with reducing both problems. There is a lot of development going on around ATO, and there are still many questions to be answered regarding its use and the way to implement that.

In this research ProRail and Lineas together with Alstom have tried to answer some of research questions regarding the usage of ATO in rail freight operation, more specifically the usage of ATO for shunting. The project was aiming to answer the question below with specific focus on the driving process and obstacle detection.

> Is it possible to automate (parts of) the shunting process using ATO?

1.2 What is ATO?

ATO is a broad term for describing the technology and process that can be used to automate parts of railway operation. ATO can be applied with different levels of automation, known as Grade of Automation (GoA). The higher the level of automation, the more tasks are taken over from the train driver. GoA2 can be seen as an advanced cruise control that contributes to increasing the reliability of train services. The train driver remains responsible for opening/closing the doors and driving the train in case of disruptions. With GoA3 and higher, one can speak of fully automatic transportation, where no train driver is needed for the train service as the train is equipped with systems to detect obstacles. This enables the train to be safely operated by detecting and responding to possible collisions with unexpected obstacles.

ATO has the potential of making more efficient use of railway capacity. By automating the driving process the spread in performance is reduced. Therefore the time reserved for one specific train can be reduced making it possible for trains to follow each other faster or to have more trains use the same shunting area. ATO also allows for the reliability and safety of railway transport to be further improved.

1.3 The project

To answer the main question, the project has been split into two parts: a desk study and a proof of concept, where the proof of concept contained most of the effort.

The desk study contained the more theoretical part of the research questions and it had a particular focus on the current shunting processes and how the future of shunting would look like with ATO. The research itself was outsourced to the Dutch engineering firm Movares. They executed the research and delivered a report with the findings (Movares, 2022). The report, that is only available in Dutch, can be found online.

The proof of concept has been the biggest part of this project. This report will fully focus on the proof of concept (PoC). The PoC, and the phases building towards the PoC, research has been focused on driving a shunting locomotive automatically and testing an obstacle detection system. The tests were performed over multiple iterations on a non-centrally operated (non-signalled) shunting area in the south of the Netherlands.

1.4 Partners

The implementation of Automatic Train Operation (ATO) has wide-ranging effects on both infrastructure managers and train operators. As a result, it is crucial to thoroughly investigate and collaboratively implement ATO. Recognizing this need for close collaboration, Lineas, a freight operator, ProRail, a infrastructure manager, and Alstom, a system supplier, have joined forces in this project. Additionally, Alstom has formed a separate partnership with ELTA to develop an obstacle detection system. By combining their extensive knowledge and expertise in train operation and ATO, this dedicated team aims to successfully achieve the proof of concept.

1.4.1 Lineas

Lineas helps companies make their supply chain climate-neutral by shifting their cargo from road to rail, reducing CO2 emissions by 90%. To this end, the company has built the largest private rail network in Europe offering customers fast, daily and reliable connections across the continent. Lineas has nearly 2,000 employees and is headquartered in Belgium with offices in France, Germany, the Netherlands and Italy.

As a freight carrier, Lineas is facing a growing shortage of train drivers. ATO may offer opportunities to address this shortage. Additionally, Lineas sees opportunities to make operations more efficient and safer through automatic shunting. Before investing in such a system, the organization wants to investigate the costs of such a system and the benefits it will yield.

1.4.2 ProRail

ProRail takes care of the construction, maintenance and management of the Dutch railway network. As an independent party, ProRail divides the space on the tracks, arranges all train traffic, builds and manages stations and builds new tracks. ProRail maintains existing tracks, switches, signals and level crossings.

For ProRail, there is a need within the ATO program to investigate the potential of ATO for various rail applications, including shunting. Additionally, the ATO program has various research questions regarding the required functionalities for ATO at GoA3/GoA4.

1.4.3 Alstom and ELTA

Leading societies to a low carbon future, Alstom develops and markets mobility solutions that provide the sustainable foundations for the future of transportation. Alstom’s product portfolio ranges from high-speed trains, metros, monorails and trams, to integrated systems, customised services, infrastructure, signalling, and digital mobility solutions. Alstom has 150,000 vehicles in commercial service worldwide. With Bombardier Transportation joining Alstom on January 29, 2021, the enlarged Group’s combined proforma revenue amounts to €14 billion for the 12-month period ended March 31, 2021. Headquartered in France, Alstom is now present in 70 countries and employs more than 70,000 people.

Founded in 1967, ELTA Systems Ltd., a group and subsidiary of Israel Aerospace Industries, is one of Israel’s leading innovative defence companies and a global leader in the field of Intelligence, Surveillance, Mission Aircraft, Target Acquisition and Reconnaissance, Early Warning and Control, Homeland Security (HLS), Autonomous Ground Vehicles, Cyber Defence and Intelligence applications. The railway automation market's growing needs for high-end technology solutions has led ELTA to establish NIART, a spinoff venture, to offer commercial solutions to this market. NIART is leveraging the technological backbone and the know-how of the multidisciplinary systems design to develop a cutting-edge Radar-Empowered Long Range Perception systems for Railway

1.4.4 Others (SafeLines, DEKRA, IL&T)

This research could not have been conducted without the help of a few additional companies. The railroad safety in the test area was managed by SafeLines.

DEKRA as AsBo reviewed the safety documentation and procedures for equipping the test locomotive with the test equipment.

Based on the safety documentation and procedures Inspectie Leefomgeving & Transport (IL&T), the Dutch NSA, provided us with an exemption transport and drive the test locomotive with test equipment installed.

1.5 Reading guideline

This report follows the structure of a standard research report. After the introduction a chapter is dedicated to the methodology of the research, followed by the results and finishing with conclusion and recommendations chapter. The Attachment contains more detailed information about the (execution of the) project.

1.6 List of abbreviations

AS	Automatic Shunting
AsBo	Assessment Body
ATB	Automatische treinbeïnvloeding; Dutch ATP-system
ATO	Automatic Train Operation
ATO-GW	ATO Gateway
ATO-OB	ATO On-Board
ATO-TS	ATO Trackside
ATP	Automatic Train Protection
BR203	Type of locomotive
CBTC	Communications-Based Train Control
DAC	Digital Automatic Coupler
DMI	Driver Machine Interface
EMU	Electric Multiple Unit, type of train
EO	Electro-Optical
ETCS	European Train Control System
ETCS OB	European Train Control System On Board
FFFIS	Form Fit Functional Interface Specification
FMCW	Frequency-Modulated Continuous-Wave
G1206	Siemens locomotive model
GPS	Global Positioning System
HLD77	NMBS/SNCB HLD77 locomotive model
IL&T	Inspectie Leefomgeving en Transport; Dutch NSA
JP	Journey Profile
MVB	Multifunction Vehicle Bus
NCBG	Niet-centraal bediend gebied; Dutch for non-centrally operated area
NSA	National Safety Authorities
ODS	Obstacle Detection System
PoC	Proof of Concept
RADAR	Radio Detection and Ranging
RIU	Relay Interface Unit
SP	Segment Profile
TCMS	Train Control and Management System
TMS	Train Management System

2 Methodology

In the introduction the main research question and research goal was presented:

> Is it possible to automate (parts of) the shunting process using ATO?

To answer that question, the following steps have been taken:
1. Create a breakdown of the main research question into multiple research questions
2. Select questions for desk study
3. Select questions for proof of concept
4. Execute desk study
5. Execute proof of concept (iterative)
6. Gather the results and write report

The proof of concept has been executed as a joined project by Lineas, ProRail and Alstom. Lineas delivered the locomotive, wagons and the personnel to run the locomotive. ProRail was in charge for creating a safe working environment (e.g. possessions and safety personnel) and general coordination of the tests. Alstom was responsible for engineering the equipment and software required to run the locomotive.

This chapter covers the project scope and characteristics (2.1) and the research questions (0). Also, it contains descriptions of the system prototype (2.2), the freight locomotive (2.3) and the test area (2.4).

2.1 Project scope and characteristics

The scope of the project is to research the possibilities of automatic shunting with a focus on driving the locomotive and obstacle detection in a test setup (not real operation).

The nature of freight trains, their operating environment, and specific tasks of the drivers bring additional challenges to implement ATO. Shunting freight trains are often old and not equipped with modern and standardized TCMS (Train Control & Management System). Therefore, obtaining inputs and providing outputs by ATO is challenging.

Moreover, these trains are usually equipped with manual couplers. The coupling procedure requires more effort compared to automatic couplers.

Besides, freight locomotives are often driven by diesel engines and their length is variable. Developing speed profiles and regulation of traction and braking effort is another demanding task.

In addition, implementation of ETCS (European Train Control System) on freight trains is prolonged and not always foreseen. Some freight trains operate on tracks with no automatic train protection system (ATP). In contrary, the mainline ATO is developed over ETCS. As a result, ATO cannot receive vital information without ETCS.

In this proof of concept, all challenges mentioned above are present:
- The test train is an freight locomotive (without TCMS)
- The locomotive does not have ETCS-OB (it is equipped with Dutch national ATP-system)
- The test environment is a not signalled area (no ATP on trackside) & it includes different type of manual switches (diamond switch, single switch and crossing switch)
- The test scenarios include locomotive movement without wagons, accurate stopping, precise stopping for coupling, etc.
- The test is executed with a prototype ATO-system that was based on a generic ATO system under development for GoA2 mainline commercial applications (e.g. for CFL High-Capacity EMUs and Digital Node Stuttgart).

What is in this research:

- Driving the locomotive (automatically) at speeds up to the local maximum of 30 km/h
- Detecting obstacles (humans, wagons, cars, point switches)
- Detecting point switch direction
- Stopping the train in case of obstacles
- Approaching a wagon for coupling
- Personnel inside the locomotive for testing and monitoring

What is not in this research:

- Receiving and complying to the (verbal) movement authorisation
- Interfacing with the locomotives (class B) ATP-systems
- Automatic shunt planning
- Fully driverless operation
- Physically coupling the locomotive and wagon (automatically)
- Driving with coupled wagons
- Pushed shunting movements
- Interfacing with the back-office for (updates of) the planning
- Detecting signs and signals
- Driving the locomotive at speeds higher than 30 km/h
- Quantitative proof for detecting obstacles and points (statistical data)

To give a more visual understanding of the scope of this project, the table below lists the different grades of automation used within ATO together with the actor executing certain tasks. The red borders indicate how at what level the task has been executed within this project.

Grade of automation	**Shunting Operation**	**Preparing the locomotive**	**Preparing the train**	**Setting locomotive in motion**	**Driving and stopping locomotive**	**Coupler Level**	**Coupling and decoupling**
GoA 0	OS On-sight shunting operation	Shunter Driver	Shunter Wagon technician	Shunter Driver	Driver	Screw coupler	Shunter
GoA 1	NSO Non-automated shunting operation	Shunter Driver	Shunter Wagon technician	Shunter Driver	Driver	Screw coupler	Shunter
GoA 2	SASO Semi-automatic shunting operation	Shunter Driver	Shunter Wagon technician	Shunter Driver	Driver Automatic	DAC 4 / DAC 4.5	Shunter
GoA 3	SSSO Single-staffed shunting operation	Shunter Driver	Shunter Wagon technician	Shunter Driver Automatic	Automatic	DAC 5	Driver Shunter Automatic
GoA 4	USO Unattended shunting operation	Automatic	Automatic	Automatic	Automatic	DAC 5	Automatic

Table 1 Classification of Grade of Automation paired with Shunting operations modified from DACIO - Matthias Reichmann; Highlighted with red borders the scope of this project

2.2 Prototype system description

Alstom already introduced and deployed an architecture in 2018. This architecture was used as part of an innovation project with ProRail and rail freight operator RRF (ProRail, 2020). A diesel locomotive BR203 with ETCS from RRF, equipped with ATO, was driven automatically along Betuweroute. The significance of this project was that being conducted during normal freight traffic.

The same architecture was adapted for NL Automatic Shunting PoC to address the unique challenges mentioned beforehand. The developed architecture is shown below:

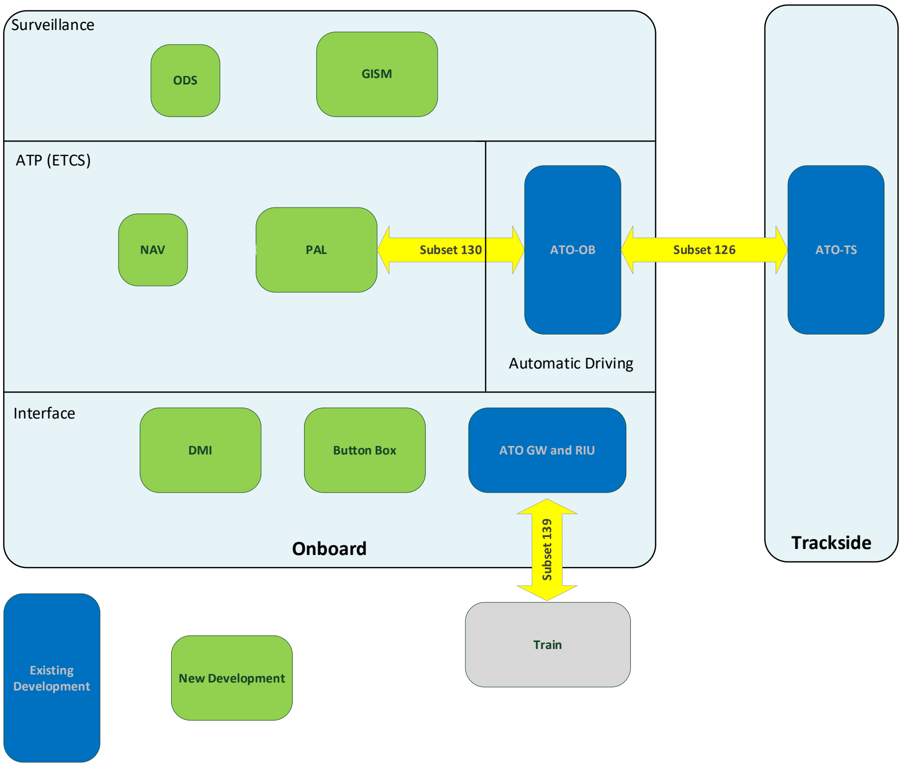

Figure 1 System architecture

NAV (Navigation): This subsystem determines the location and speed of the train using GPS coordinates. NAV is developed as there is no other mean to acquire such information.

PAL (Protection Abstractive Layer): PAL is the ETCS (ATP) simulator. It provides subset-130 (ETCS-OB / ATO-OB FFFIS Application Layer) information to the ATO-OB. This information includes maximum allowed operating speed and allowed distance to be travelled. By definition, if any of the limits are exceeded, emergency brakes are applied to stop the train.
PAL is also equipped with signal detection system to interpret signals (not used for this proof of concept).

ODS (Obstacle Detection System): An obstacle detection system is a cutting-edge technology that is rapidly gaining popularity in various industries. It is a highly sophisticated and advanced technology, designed to detect and identify objects in a designated area, with the purpose of avoiding potential collisions.
An obstacle detection system includes one or more sensors including Ultrasonic sensors, LiDAR, Radar and Stereovision. In this PoC, the ODS included Radar and Stereovision.

Radar (Radio Detection and Ranging): RADAR is a technology that uses radio waves. Radio waves can be used for a relatively longer distance as the absorption rate when contacting objects is lower. RADAR works on the basis of Doppler effect and can determine object's distance and speed.

Stereovision: Stereovision involves using two or more cameras to create a 3D view of the environment and detect obstacles. Infrared or thermal cameras are used to enable self-driving at night. These cameras absorb the thermal radiation of objects.

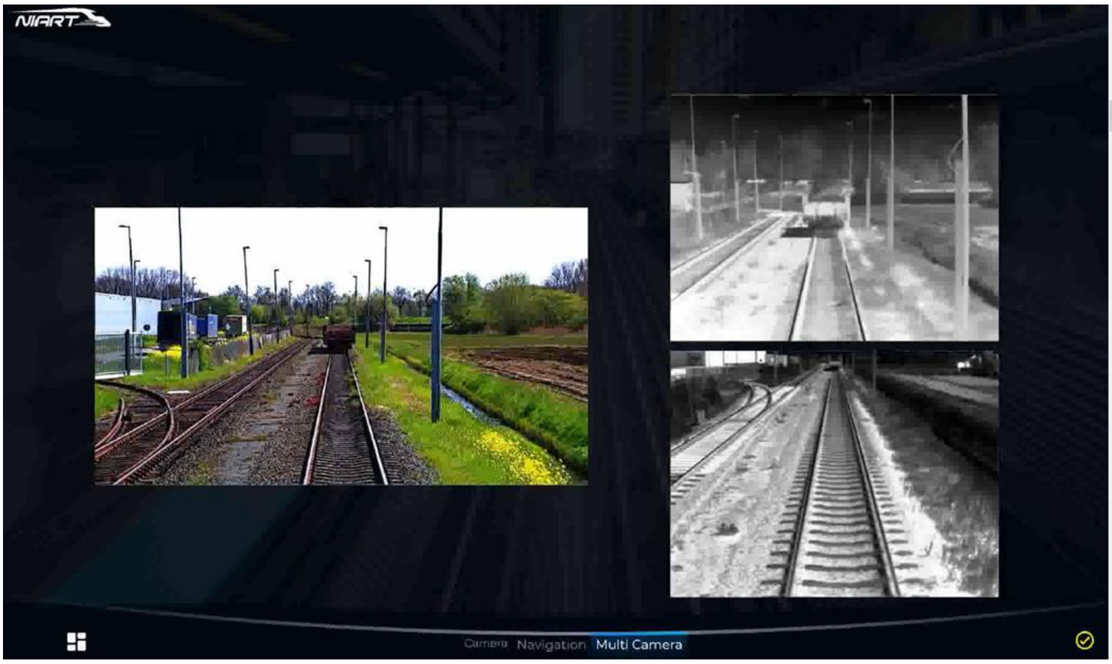

Figure 2 Example of ODS system at work

As shown in the picture above, ODS is monitoring the environment, looking for objects within the track perimeters (track gauge + 1.5m). It detects obstacles and classifies then when known (human / rock is a known obstacle) and the distance to them.

GISM (Global Installation Surveillance Manager): GISM interprets the ODS data and the appropriate action which has to be taken: stopping in front of an obstacle, continuing the train movement when switches are correctly aligned, etc.
Due to the presence of manual switches in this PoC, PAL and GISM include specific features to analyse switch positions.

ATO-GW (Gate Way) and RIU: The ATO-GW and RIU are developed as an adaptor to interface with the train, complying with subset-139 (ATO-OB / ROLLING STOCK FFFIS APPLICATION LAYER). They interface to the train to provide ATO-OB with information such as Traction/Brake Level, slip and slide, door status, brake status. They apply the traction / brake command and provide feedback to the ATO-OB. They transfer ATO-OB commands for traction and braking to the train.

DMI (Driver Machine Interface) and ATO-button box: This subsystem provides means to interact with the ATO. The DMI displays the state and other indicators related to ATO. The button box was developed to allow the test leader to intervene by disengaging ATO.

ATO-OB (On-Board): The ATO-OB determines the speed profile based on various inputs (location, movement authority, train speed, brake position, etc.) to execute a JP. It then calculates the required traction / braking force to be applied.
Besides, it provides status reports to the ATO-TS indicating the estimated arrival times as well train speed, location, etc.

ATO-TS (Track Side): The ATO-TS provides the JP (Journey Profile) and SP (Segment Profile) to the ATO-OB complying with subset-126 (ATO-OB / ATO-TS FFFIS Application Layer).
The JP includes the route which has to be travelled by the train, the stopping points passing points, arrival times, departure time, door operation and possible speed restrictions are part of the JP.
The travelled route is expressed in terms of SP. The SP includes details about the track such as track identification details, speed profile, gradients, curves, etc.
The ATO-TS receives status reports from ATO-OB. These status reports can be used to enhance traffic regulation (not part of this PoC).

For the Proof of Concept, several JP and SPs were defined to evaluate the performance of the ATO. These scenarios included:

- Running on clear tracks with/without wagon(s) and stopping accurately
- Running on tracks with/without wagon(s) and stopping accurately while obstacle(s) is present
- Running on tracks with/without wagon(s) and stopping accurately while switch(es) is incorrectly aligned
- Running on tracks with/without wagon(s) approaching wagon(s) for coupling

For a given JP, the ATO system first inspects the route to be travelled. The ODS observes the track, looks for obstacles within the track, the switches and their position. The ATO starts the train only if there is sufficient clear track ahead of it. The ODS continues to monitor the track throughout the journey.
In case of an obstacle or an incorrect switch position, the ATO system applies the brakes to stop the train. The braking force is calculated to ensure the train stops right before the obstacle / switch while avoiding collision / derailment.
To stop at a stopping point, the ATO system determines the remaining distance to the stopping point & regulates the braking effort to stop the train. In order to achieve accurate stopping, the braking curves are determined by characterizing the train behaviour. This enables ATO to calculate the exact braking effort that is needed to stop the train. The same process is applied when the JP includes timing point used for coupling and decoupling.

Deploying this modular approach provides flexibility to deploy ATO on trains with no or without modernized TCMS. Not only the train manoeuvres can be automated, but the trains can be brought to the coupling / decoupling location in a way that only the manual coupling / decoupling function is left to be performed.

2.3 Freight locomotive HLD77

The majority of the tests are executed with a HLD77 locomotive from Lineas. This is a diesel hydraulic locomotive designed for shunting and freight work, and it is primarily used in Belgium. The locomotive is manufactured at the Maschinenbau Kiel. The locomotive has an off-centre single cab design, which is ideal for fast reversing (Dutch: kopmaken).

The locomotive used for the tests is allowed to operate in The Netherlands and it is equipped with all necessary systems like cab radio and the Dutch ATB train protection system. For the purposes of the test the locomotive has been refitted with the systems described in the previous section.

Figure 3 HLD77 with prototype systems at Oosterhout Weststad

2.4 Test area: Oosterhout Weststad

The tests have been executed at the Dutch shunting yard of Oosterhout Weststad. This is a yard separated from the main line with a 15 km “stamlijn” that starts at Lage Zwaluwe. The yard gives access to a number of companies with a rail connection. In general around 3 commercial trains per week are operated in this area.

The shunting yard is a non-signalled area (Dutch: NCBG, Niet-Centraal Bediend Gebied), which means that there are no signals and that there is no active ATP-system: the driver has full responsibility for a safe movement of the train. That includes making sure the switches are directed in the proper position and that there are no obstacles on the route.

On this specific yard the point switches are manually operated electronically point machines. Besides that there are two tracks that are part of the test area, which also includes two unprotected level crossings which are located near emergency exits of the nearby companies.

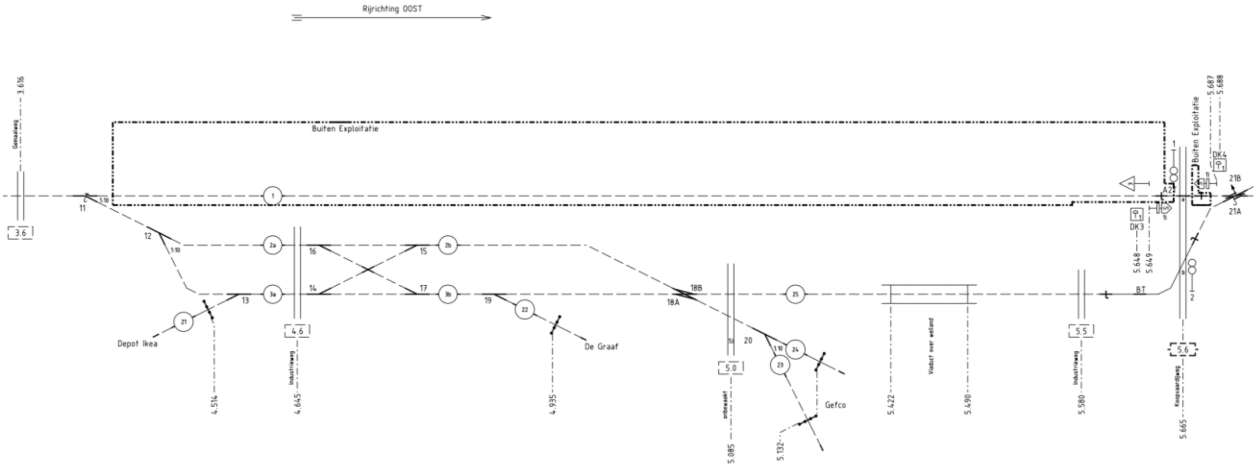

Figure 4 Signalling layout Oosterhout Weststad

Figure 5 Industrialized zone of Oosterhout Weststad

2.5 Research questions

Research questions were created in an early stage of the project. The research questions provided focus and a common understanding of the scope of the project.

The research questions were focused on different topics. Below the topics that were researched in the test project.

- Preparing for departure
- Receiving and following driving authorization
- Detecting switch positions
- Driving the locomotive
- Reversing
- Coupling and uncoupling
- Detection, recognition, and prediction of obstacles

The scope for defining the research questions was broader than that of the proof of concept. To ensure traceability, the original numbering for the research questions has been used. As a result, there are gaps between the numbers.

Preparing for departure

AS-1.2.1 Which steps need to be executed (automatically) to prepare the locomotive for departure under ATO? Which systems need to be started up and what (manual) input/operation do these systems require?

Receiving and following train authorization

AS-1.3.2 Which system is responsible for accurate positioning to monitor the driving authorization of the ATO movements?

Detecting switch positions

AS-1.4.1 Can the ATO system determine the position of the point switch (left/right)?
It is logical to detect the switch position with cameras and image recognition.
AS-1.4.2 At what distance, speed and reliability can this be detected?
Experienced drivers can detect the switch position via the switch tongue at a distance of more than 100m.
AS-1.4.3 How does ATO respond if the switch is not in the desired position?

Driving the train

AS-1.5.1 Can the ATO system drive accurately at lower speeds *(<20 km/h)?*?
AS-1.5.2 Can ATO stop accurately enough at the desired location?
The accuracy for goods will vary from about 20m for positioning on the track to 1m at locations where container trains are unloaded.
AS-1.5.3 Also when driving towards wagons? It may not be possible to stop at the exact position, but at a measured distance to the wagon.

Reversing

AS-1.6.1 What procedures does ATO need to perform to change direction of travel?
AS-1.6.2 What is technically required to enable ATO to reverse?
AS-1.6.3 Can the ATO system control the necessary systems?

Coupling and uncoupling

AS-1.7.2 Can ATO approach a wagon accurately enough for coupling?

Obstacle detection, recognition, and prediction

AS-1.8.1 At what distance can obstacles be detected and how long does the system need to recognize obstacles? Does this vary by type of obstacle?
AS-1.8.2 Is the obstacle detection system able to determine this with sufficient certainty (false positives and false negatives)? Does this vary by type of obstacle?
AS-1.8.3 Is the detection distance and speed sufficient to come to a stop before the obstacle is reached? In which cases yes/no? *This depends on the speed of the train.* It may be possible to adjust it to increase safety. How does this safety level compare to the current situation with the driver?
AS-1.8.5 How well can the system handle different types of weather conditions (e.g. rain, fog, snow, low sun)?
AS-1.8.6 Does the chosen system solution have limitations? If so, what limitations does the system have and how do these limitations compare to possible alternative system solutions?

3 Results

This chapter covers the answers to the research questions for the proof of concept. The Attachment contains a day-by-day overview of the execution phases. The results of those execution phases are used to answer the research questions.

The research questions were focused on different topics. Below the topics that were researched in the test project.

- Preparing for departure
- Receiving and following driving authorization
- Detecting switch positions
- Driving the locomotive
- Reversing
- Coupling and uncoupling
- Detection, recognition, and prediction of obstacles

Preparing for departure

AS-1.2.1 Which steps need to be executed (automatically) to prepare the locomotive for departure under ATO? Which systems need to be started up and what (manual) input/operation do these systems require?

There are two types of systems that need to be prepared before operation:

- Locomotive specific systems
    - Enabling electrical circuits
    - 24-hour check (e.g. oil level and diesel level)
    - Starting the engine
    - Starting ATP-system(s)
- ATO/ODS related systems
    - Starting the equipment
    - Performing a calibration run

After all systems are running, for the train to make its first run, several additional steps are needed:

- Brake test
- The train must receive a Journey Profile (JP) and Segment Profile (SP). This means that the train is receiving instructions from the trackside on which tasks it needs to perform and where it needs to drive. This JP must be created automatically based on the planned schedule for the day.
  The Segment Profiles represent the (static) information about the layout of the area. To create the Segment Profiles accurate data is required about the position of trackside elements like point switches, level crossings. This information is available when driving on an ETCS-track but not on a non-centrally operated area.

During this project all steps above were executed manually. Should this system move towards an implementation phase then for a GoA3-solution manually executing these steps is still possible. If GoA4 is requested, then the above steps should get automated.

Receiving and following train authorization

AS-1.3.2 Which system is responsible for accurate positioning to monitor the driving authorization of the ATO movements?

The test was executed in a non-centrally controlled, non-signalled area. So, for the scope of these tests there was no active ATP-system to receive or monitor the driving authorization, nor to provide positioning information.

The PAL-system is an ETCS (ATP) simulator that was configured to simulate the movement authority. Information like location and speed was provided by the NAV-system, which was generating that information using a GPS-receiver. The details of this architecture can be found in 2.2.

Using a solution with GPS for positioning and speed was sufficient for this project. However, feedback from the test team was received that easier and better performance can be reached when using a dedicated system that is based on train odometrie information and fixed location markers. This would be the same principle as being used in the ETCS-systems.

Detecting switch positions

AS-1.4.1 Can the ATO system determine the position of the point switch (left/right)?

The prototype system was able to detect the position of point switches using an Obstacle Detection System (ODS). This subsystem was based on cameras and radar. Train drivers are educated to look at the blade of the switch to determine the driving direction. The ODS-system was not able to do this, but it was able use the flags located on top of the point machine for this.

The ODS detected, classified, and reported obstacles and switch positions within a given route. The switches and their position are detected between 150-120m before reaching them. This was sufficient for the operational speed in this project of 30 km/h. It stopped the train when switches for a given route are in the incorrect position and when obstacles are placed in the gauge.

ATO did correctly discard switches in adjacent routes and obstacles "out of gauge".

AS-1.4.2 At what distance, speed and reliability can this be detected?

The position of the switches was detected between 150-120m at speeds between 20 and 30km/h. Reliability good, meaning that during the tests there were no issues with reliability. There are several tests performed in similar situations. No statistical conclusions can be made based on the available data.

AS-1.4.3 How does ATO respond if the switch is not in the desired position?

During the tests it was configured and demonstrated that ATO will stop the train if the switch is not in the desired position.

Driving the train

AS-1.5.1 Can the ATO system drive accurately at lower speeds (<20 km/h)?

During the testing the ATO system was driving at lower speeds during starting, stopping, and coupling to the wagons. The developed driving library was advance enough drive at speeds below 10km/h.

AS-1.5.2 Can ATO stop accurately enough at the desired location?

During the early testing there were inaccuracy challenges due to train braking system limits and unavailability of odometer data. But during the final demonstration a stopping accuracy below 1m was achieved. This is sufficient for expected maturity level of the prototype system.

AS-1.5.3 Also when driving towards wagons? It may not be possible to stop at the exact position, but at a measured distance to the wagon.

The system was able to detect wagons. The wagon located in gauge is detected at a distance of around 450m (classification as a wagon is done between 350 and 400m). Combined with the ability to stop below 1m this should be possible.

However, this was not extensively tested due to time constraints. In the final test there have been some hard coded parameters regarding stopping to wagons, but the potential has been demonstrated.

Reversing

AS-1.6.1 What procedures does ATO need to perform to change direction of travel?

In this prototype system, the traction and brake handle from the cabin with the short nose is connected to the ATO-OB via the RIU such that the ATO-OB can take control of the locomotive; the change of direction is thus performed via a backward movement command from the short nose (as a shunting driver would do on such locomotive).

This functionality was tested using the coupling tests. Due to the lack of an automatic coupler, the operator had to confirm a successful coupling with the “coupling confirmed” button on the ATO button box. After that, the ATO changed the travelling direction (selecting backward driving direction and selecting ODS-sensors on the other nose) and drove the train in the opposite direction until the end of journey was reached.

The two things required during this test were:

- A journey profile that contained a different driving direction
- A manual confirmation that coupling was successful

The chosen solution and the procedures involved are sufficient for maturity of this prototype system. For future solutions the confirmations by the operator should be replaced by automatic checks.

AS-1.6.2 What is technically required to enable ATO to reverse?

Reversing the locomotive can technically be done in two ways. The long way would be to close the active cabin of the locomotive and open the cabin at the other side and perform all the checks needed for a regular start of a drive (also see AS-1.2.1). The short way is to keep the active cabin open, switch the driving direction lever to reverse, activate the ODS on the other side, and execute the movement as a backwards movement.

The solution to choose depends on the type of movement and on the type of ATP-system. When reversing is allowed by the active ATP-system (or when no ATP-system is active), then it is sufficient to “switch” the driving direction of the locomotive and execute the movement as driving backwards.

For the scope of this shunting proof of concept, going for the short solution was sufficient.

AS-1.6.3 Can the ATO system control the necessary systems?

As mentioned in the previous answers, the prototype ATO-system was able to control all the systems needed to move the locomotive backwards.

The prototype system is not able, nor designed, to close cab, open another cab and configure the locomotive’s ATP-systems with the required information. However, for the scope of this shunting proof of concept this was sufficient.

Coupling and uncoupling

AS-1.7.2 Can ATO approach a wagon accurately enough for coupling?

During the final demonstration, the prototype system was able to drive and stop the locomotive close to the wagon for coupling. It was configured that the locomotive should stop at a distance from the wagon, and (after confirmation from the operator) to commence the final approach to the wagon. The accuracy achieved was within 0.5 meter. For higher accuracy, the determining of the position (or distance) to a wagon needs to be improved.

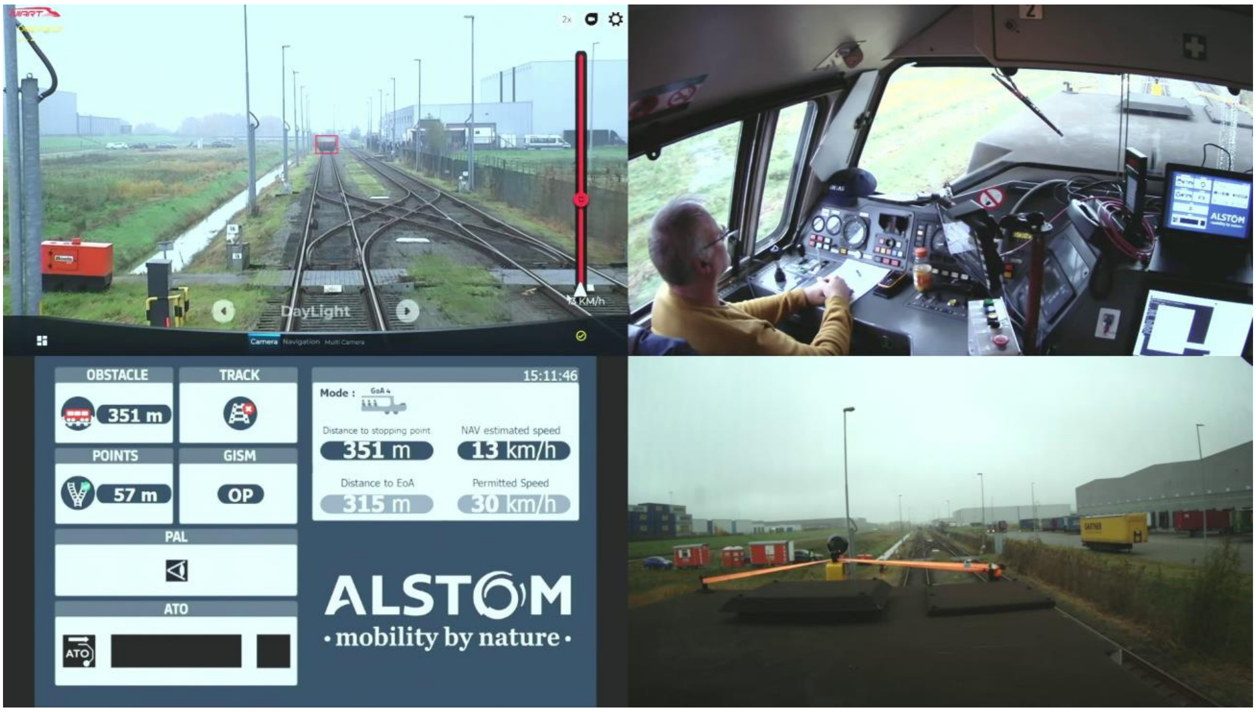

Figure 6 Approach wagon for coupling during PoC

Obstacle detection, recognition, and prediction

AS-1.8.1 At what distance can obstacles be detected and how long does the system need to recognize obstacles? Does this vary by type of obstacle?

During the PoC, obstacle detection was an important part. The testing showed the following results:

- Detect people: human located in gauge, standing or moving, are detected around 300m (classification as a human is done around 250m depending on the cases).
- Detect wagon: the wagon located in gauge is detected around 450m (classification as a wagon is done between 350 and 400m).
- Detect car: the car located in gauge at the crossing is detected around 300m (classification as a car is done between 300m).
- Detect switches: the switches and their position are detected between 150-120m.

These tests are executed with speeds up to 30 km/h. The results might differ when the operating speed is higher than 30km/h.

AS-1.8.2 Is the obstacle detection system able to determine this with sufficient certainty (false positives and false negatives)? Does this vary by type of obstacle?

No statistical answer can be given to this question. However during the testing only very limited false positive detections of an object were detected. Please note that this was on the side of the ‘short nose’. The long nose is equipped with only the optic part from an ODS and therefore the performance is more limited.

Interference due to overhanging grass and therefore blocking the line of sight for some of the systems was observed.

False negatives are not observed for the types of objects which have been considered for the Proof of concept e.g. human, cars, wagon, as long as the objects are in the “field of view” of the ODS. Detection in curves has not been tested.

The ODS system is "trained" with the obstacles as used for the tests. To detect specific other objects and execute a reaction, the ODS system has to be trained.

AS-1.8.3 Is the detection distance and speed sufficient to come to a stop before the obstacle is reached? In which cases yes/no?

The relationship between safety, distance and speed has not been assessed in sufficient detail to reach a definitive conclusion, given the fact that this was an early PoC exploring the technology. However, based on the tests the system is able to accurately assess and stop before objects at an operational speed of 30 km/h.

During the test execution, no unsafe working of the system has been detected by the driver and Test Coordinator (i.e. the emergency button has not been used).

AS-1.8.5 How well can the system handle different types of weather conditions (e.g. rain, fog, snow, low sun)?

During the final demonstration day the team was surprised by very heavy fog. During the tests performed during this fog the system performed just as well as without fog. The system was able to detect objects in the fog when the human eye wasn't able to. The precision of the detection was not changed compared to the previous findings. Though difficulties detecting obstacles with low sun have been observed. The details posted in 1.8.1 include the results in these bad weather conditions.

Figure 7 Fog during media event

AS-1.8.6 Does the chosen system solution have limitations? If so, what limitations does the system have and how do these limitations compare to possible alternative system solutions?

There are some limitations to the system used:

- The system itself is in the early prototype stage. That means that manual configuration and operation work needs to be performed. This is typical of explorative research and proof-of-concept. The system also needs to be trained to be able to allow for obstacle detection.

- For automatic shunting operation, both wagons and the locomotive must be equipped with an Automatic Coupling system (Digital Automatic Coupling, DAC). Both wagon and locomotive were not equipped with a DAC. Therefore, this test could not be performed. To be able to test this, additional test equipment and system design is needed.

- Prior to on-site testing, lab tests and developments continued within ALSTOM. In this case, with the use of a locomotive where limited information is available about the braking and traction behaviour of the locomotive, ATO needs integration tests in this locomotive.

4 Conclusions and recommendations

Progress has been made in the direction of automated driving on shunting yards through the proof of concept and desk study phases. However, upon thorough analysis, it is evident that there remain several challenges to be addressed in order to enable driverless operations (GoA3) in non-signalled shunting yards, such as Oosterhout Weststad. The lack of both a signalling system and an automatic train protection system presents several drawbacks that will ultimately prevent ATO from ensuring safety.

Still this study is a success. To our knowledge this is the first time that a test like this has been performed on a non-signalled shunting yard. The team managed to retrofit a prototype system to a freight locomotive that adds obstacle detection and ATO-operation to its abilities and that it is possible to automatically move it on a shunting yard.

During the multiple stages of testing the prototype system learned to detect and recognise obstacles like humans, cars and wagons. In the end the system was able, even with changing weather conditions (including fog), to detect those obstacles and stop the train in due time. And answers have been given towards the research questions.

During the test, a number of challenges for shunting under GoA3 with the tested system have been determined. These will require further research to resolve, either by further improvement of the tested system or by a different approach to the system. Furthermore, some of these challenges originate from the use of the system on a non-signalled shunting yard. By shunting on a signalled shunting yard, these challenges will not exist (in this form). The main challenges are:

- The main concern is point detection. Currently the train driver is obliged to observe the blade of the point to assess whether it is safe to continue. The prototype system has limitations to do so especially in complex areas like diamond crossings. During the PoC it was solved by looking at the point flags. For future testing or implementation this problem can be solved by either operating the system in a signalled area or to gather much more data.
- Knowing the exact position of the train and stopping at the exact location of choice was proven to be difficult. Main difficulty was the lack of proper odometry on board of the train. Nevertheless during the final days of testing a stopping accuracy was achieved of less than one meter without addition or changing the existing odometry system of the locomotive. It would have been a lot easier having an ATP-system active that also reports it position and to have a locomotive with a digital interface (TCMS) for controlling acceleration and deceleration.
- Detection rates were good. But there are scenario’s where the prototype system was struggling. Obviously due to the system setup it is not able to look around corners. So in curves, detection is limited. External circumstances like overhanging grass or low hanging sun made detection of obstacles much more difficult.
- Retrofitting a 20-year-old freight locomotive has its own difficulties. Every corner or available space inside the locomotive has been filled with systems for operating the locomotive in multiple countries. For this PoC the systems were installed in an outside cubicle of the locomotive. This solution was chosen due to the nature of the PoC test to be as less as impacting the current situation of the locomotive. In a later stadium, integrating of the different systems should be possible and therefore creating also possibilities to use less space in the locomotive. Also controlling the older locomotive is much more difficult as newer locomotives are fitted with a digital controller. For this older locomotive a specific electronic interface had to be build.

Although we conclude against driverless operation on a non-signalled area based on this proof of concept, we do recognize that there are benefits to using ATO to automatically drive the train (GoA 2, GoA 3). ATO could assist the train drivers by:

- driving the train
- stopping it accurately at stopping point
- approaching wagon(s) / loco(s) for coupling
- alerting to the obstacles & bring the train to a halt

In this joint effort, the driver is responsible for safety while ATO ensures smooth and efficient execution of driving tasks. ATO could reduce the operation time, optimize fuel consumption, and decrease the wear and tear on rolling stock components.

Main recommendations for anybody willing to further investigate on this topic:

- Make sure to gather much more data, before and during testing as it will improve detection;
- Use a train with a digital controller (TCMS) as it will make installing the system and controlling the train a lot more easier;
- Focus further research for shunting with ATO to a signalled yard with an ATP-system like ETCS.

5 Reflection

The project has encountered several setbacks, with the one with the greatest impact being the global COVID-19 pandemic. Even without a worldwide virus, an innovative project like this can face significant organizational challenges. The engineering of the various systems is carried out in different countries and by different teams. And because these teams do not work full-time on this project, testing moments must be planned well in advance so that everyone can be present at the same time. COVID-19 hindered the creation of a consistent schedule, with testing moments being postponed several times and the entire schedule being disrupted because travel restrictions made it impossible to get the test team together. In addition to understaffing, the availability of machine operators was significantly affected by the virus. However, the project ultimately came together.

Another major hindrance was ultimately the absence of a train protection system such as ETCS or CBTC. As also mentioned in the conclusions, this limits the accuracy of position determination and it cannot be determined in advance whether the track switches are in the correct position. We managed to deal with this under the circumstances, but it does lead to serious reservations in the conclusions about the potential to roll out such a solution in a non-signalled area.

6 References

Movares. (2022). *De impact van ATO op het rangeerproces.*

ProRail. (2020). *ATO verkenning Betuweroute Eindrapportage.* Retrieved from https://www.prorail.nl/nieuws/eindrapport-ato-proefritten-betuweroute

Attachment: Overview of the execution phases

Phases

- Phase 1: Documentation (not covered in this attachment)
- Phase 2: Creating a video recording and digital model of the test area
- Phase 3: Training the obstacle detection system and training the ATO-driving library
- Phase 4 (PoC): Integrate ODS to the ATO, and drive the train with ATO and ODS active

Phase 2

The objective of this phase is to record real-life data from the shunting yard in Oosterhout where the proof of concept for automatic driving is going to be performed.

The data is then processed off-line by the algorithms from the Obstacle Detection System i.e. ODS. The purpose is to confirm that the performances related to the detection and recognition of objects can be achieved in the real environment.

Setup

The recording of data is performed with one camera for industrial application. This Commercial Off The Shelf equipment realizes a global shutter function, which enables high-picture-quality imaging (avoiding distortion and flash band phenomenon). We selected an equipment midrange, around 1000€, since the target is to provide solutions which are "affordable" to the market.

Several "objects" are selected to be detected as "obstacle" within and outside the track:
- Humans – for these tests, dummies are used for human
- Locomotive
- Wagon – container (open) wagon and closed wagon are used

In addition, specific recording is done for the different type of points, since the ODS has to be able to recognize the point and its position.

The video recording has to be done such that the data are pretty close to the data that will be gathered by the real ODS-system. Therefore, the camera shall be positioned at a height similar to what the height where it will be installed on the HLD77.

Execution (Nov 2020)

Recording is performed in two ways:

- **Static recording**:
  - Camera is placed on a Tripod: 2m and 2,5m.
  - Objects are placed at a pre-defined distance from the Camera (measured separately): 10m, 50m, 100m, 150m, 200m.
  - Video of 10, 30 or 60 sec are made in order to analyse in post-processing the accuracy of the distance evaluation made by the algorithm on basis of the video versus the actual distance measured on-site.

- **Moving recording**:
    - Camera is placed on a locomotive at 2,5m (on the nose of the locomotive). For these recording, a locomotive G1206 has been used (the height of the G1206 is similar to the height of the HLD77).
    - Objects are placed at a pre-defined distance i.e. 200m from the locomotive (measured separately).
    - Video is performed with train approaching the objects in order to analyse in post-processing the accuracy of the distance evaluation made by the algorithm on moving subjects on basis of the video.

Recording took place in November 2020 during day light and night.

Figure 8 G1206 approaching a dummy placed within the track gauge

Results

In total, 194 static recordings and 14 moving recordings have been performed.

The processing of the data enables us to have the following conclusions from this step:

- Detection of people: accuracy of detection and evaluation of the distance is in line with the expectation (less than 5% difference in the evaluation of distance with stable values over sampling); correct evaluation of the position versus the gauge of the track.
- Detection of wagon and locomotive: accuracy of detection and evaluation of the distance is in line with the expectation (less than 5% difference in the evaluation of distance with stable values over sampling)
- Detection of point positions: difficulties to evaluate the point position are highlighted beyond 80m in day light (worse during night conditions)

The position of the point is defined based on the position of the lever controlling the mechanical point. The size of the lever and the difference of position between a “Normal” and “Reverse” position is such that it is difficult to ascertain its position beyond 80m.

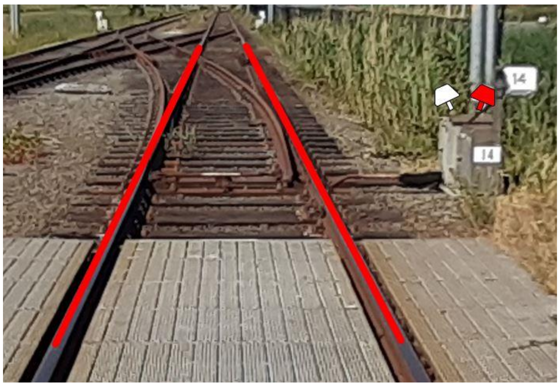

Figure 9 Point 14 in Normal (right) position

Figure 10 Point 14 in Reverse (left) position

It is especially difficult for the diamond crossing, since for this case the position of the lever of point 18A and point 18B have to be determined to evaluate the train direction.

Figure 11 Diamond Crossing 18A/18B

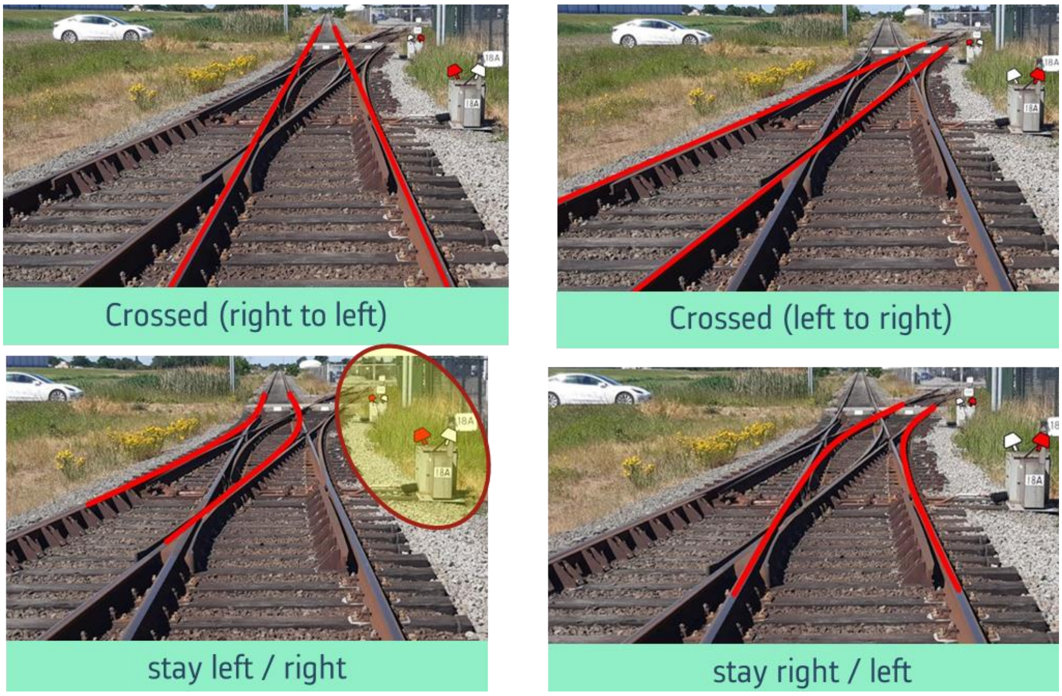

Figure 12 Determine of position of the travel direction at Diamond crossing 18A/18B

The conclusion for this step is positive:

- The performances of ODS, only based on the video, enable to detect the obstacles considered as part of the used cases for this Proof of Concept, and determine their characteristics: type, distance.

- These characteristics are such i.e. more than 200m and with sufficient level of confidence in detection (or non-detection) that it enables to perform the Proof of Concept with the foreseen operational speed of 30km/h.
- The detection of the point position is not sufficiently robust at this stage but this is a “novelty” for the ODS and all parties agreed that the elements gathered gave sufficient confidence that the performance will be improved by further tuning of the algorithm of the Obstacle Detection System.

Phase 3A, 3B and 3B+

The objective of these phases is to test the Obstacle Detection System in the real environment of the shunting yard in Oosterhout where the proof of concept for automatic driving is going to be performed.

The HLD77 is equipped with the ODS system for the first time, to verify the correct integration of all the elements of the ODS on the locomotive.

The detection capabilities of the ODS are tested on-site, enabling to refine the settings of the different sensors between based on the actual results.

Several steps are planned with a minimum of 2 months between each step, to perform off-line analysis of the data recorded to enhance the algorithm in charge of detection and recognition between each step.

Setup

The Obstacle Detection System described in paragraph 0 is composed of:

- a digital FMCW (Frequency Modulated Continuous Wave) radar,
- an electro-optic system composed of several video channels to cover the range of distance from 0m to 1000m:
  - ultra short range: 0,5m – 70m
  - short range: 8m – 150m
  - medium range: 100m – 450m
  - long range: 350m – 1000m
- a recording and processing unit.

Two specific frames have been designed to support the radar and the Electro-Optic system on the front of the locomotive, taking care that the driver’s view would not be obstructed. It was not possible to place an equipment of the size of the EO system on the nose of the locomotive. A separate cubicle is installed to place the recording unit (and necessary power conversion system).

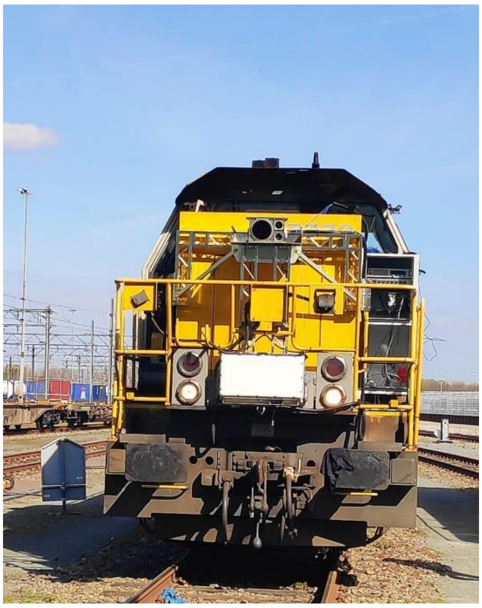
Figure 13 ODS on HDL77 (front view)


Figure 14 ODS on HDL77 (side view)

During the first test session, vibration recording has been performed to ensure that the vibration of the frame does not disturb the measurements of the radar and EO System.

Several “objects” are selected to be detected as “obstacle” within and outside the track:

- Humans – for these tests, real humans are used
- Wagon – container (open) wagon is used
- Car – located on crossing

Specific recording is done for the different type of points, since the first camera recording highlighted some difficulties to recognize the point and its position.

<u>Execution (Apr 2021, Dec 2021)</u>

Recording is performed in two ways:

- **Static recording**:
  - Objects are placed at a pre-defined distance from the Camera (measured separately): 10m, 50m, 150m, 200m, 300m and 600m (for detection of wagons only).
  - Video of 30 sec are made in order to analyse in post-processing the accuracy of the distance evaluation made by the algorithm on basis of the video versus the actual distance measured on-site.
  - Several tests are performed mixing obstacles and with “moving” obstacles:
    - Human standing and walking, crossing the gauge
    - Human standing near wagon
    - Human next to car
    - Human standing in front of wagon
- **Moving recording**:
  - Objects are placed at a pre-defined distance i.e. 200m from the locomotive (measured separately). HLD77 is approaching the obstacle at several velocities i.e. 10km/h, 20km/h, and 30km/h.

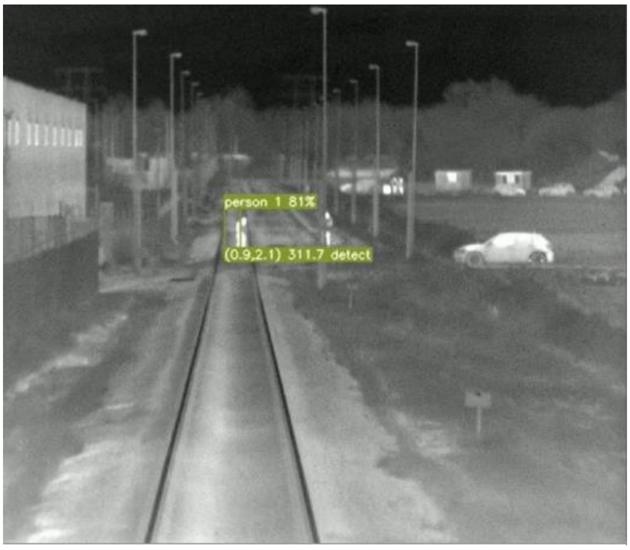

Figure 15 ODS recording (night session)

Figure 16 ODS recording (daylight session)

Results

A first session was performed in April 2021. Due to logistic issue with the locomotive, the second session planned in October 2021 has been cancelled and has been shifted to December 2021.

The processing of the data enables to have the following conclusions from this step:

- Detection of people: the persons located in gauge, standing or moving, are detected around 300m (classification as a human is done around 250m depending on the cases).
- Detection of wagon: the wagon located in gauge is detected around 450m (classification as a wagon is done between 350 and 400m).
- Detection of car: the car located in gauge at the crossing is detected around 300m (classification as a car is done between 300m).

In all cases, the error on the estimation of the distance to the object is less than 1% when using the fusion of radar and optics data, the radar-based accuracy being more efficient than the optics one.

Some difficulties were highlighted in the previous phase regarding the detection of point positions, therefore several specific cases were tested to refine the performance:

Figure 17 Detection of point position (both images)

The position of the points could be detected (whatever the position) between 120/150m in 95% of the cases and it reached 99% between 50m/70m.
The lower and upper values are obtained at 40km/h and 20km/h: the distance is longer at a lower speed.

Some recordings have been performed outside the planned test area, when arriving on Oosterhout, which have highlighted a performance issue for the detection function: in curve with reduced radius, the ODS has a reduced visibility of the track gauge (or no visibility depending on the radius).

Figure 18 Detection in sharp curve

This behaviour needs to be considered at ATO system level: how the ATO should behave when the ODS has no visibility in curve.

The outcomes of the measurements campaign made during this step is positive:

- The performances of ODS have been demonstrated in real environment, confirming that it is able to detect the obstacles considered as part of the used cases for this Proof of Concept, and determine their characteristics: type, distance.
- These characteristics are such i.e. 300 to 500m and with sufficient level of confidence in detection (or non-detection) that it enables to perform the Proof of Concept with the foreseen operational speed of 30km/h.
- The detectability of multiple objects has been demonstration with the target obstacles. Some enhancements have been made thought the use of InfraRed Camera to enable detection of people in front of wagon.
- The detection of the point position has been enhanced over the two sessions and it reaches a level of performance sufficiently robust to perform the scenarios planned for the Proof of Concept.

Phase 3C

The objective of this phase is to continue to test the Obstacle Detection System in the real environment of the shunting yard in Oosterhout where the proof of concept for automatic driving is going to be performed.

The HLD77 is equipped with the ODS system on both sides of the locomotive i.e. short nose (like phase 3A) and long nose.

To progress on the control of the locomotive by the ATO On-Board, the ATO is also installed during this phase to perform the “characterization” tests: the ATO-OB software needs to acquire the dynamic behaviour of the locomotive when applying traction and brakes to be able to respect the target speed and the stopping points when the ATO must control the locomotive movements.

In this phase the ATO-OB will be installed in a GoA2 configuration. The ATO-OB is not connected to environment detection system in this phase.

Setup

In addition to the equipment mentioned in §4.2, a second frame is installed on the other side (long nose) of HLD 77 to install the ODS. This ODS includes an electro optic system, as shown below:

Figure 19 ODS on long nose

The separate cubicle installed to place the recording unit is also used to accommodate the Relay Interface Unit (RIU) and the hardware embedding the software for ATO-OB, ATO-GW and NAV:

Figure 20 Cubicle

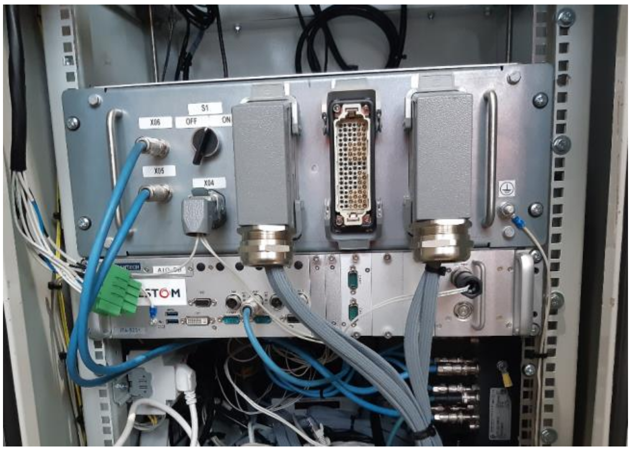

Figure 21 RIU and ATO Computer

The RIU is a standard Alstom rack designed for ATO projects where the ATO system has to control the traction and brakes via a wired interface (contrary to modern rolling stock where the ATO is connected to the Train Control and Monitoring System TCMS via an ethernet or MVB bus).
The traction and brake handle from the cabin with the short nose is connected to the ATO-OB via the RIU such that the ATO-OB can take control of the locomotive. Some pressures sensors are added to the brake monitoring circuit to give fast feedback to the ATO-OB: the ATO needs to monitor in real-time that the command sent to the brakes are actually applied.

A button box has been designed for this project to give an interface to the test driver and to the test leader. Since the ATO system is under tests, the driver is responsible of the safety of the train ride and needs to interact with the ATO-OB e.g. driver action is required to launch a test. The button box also gives the possibility to isolate the ATO-OB from the traction and brake control (via the RIU) such that the driver can take back the control of the locomotive at any moment.

Figure 22 ATO Button Box

Thanks to the design of the RIU, all these modifications are made without altering the integrity of the HLD77 locomotive, such that the material can be removed at the end of the test session and the locomotive can be used for normal journey.

The obstacles in Phase 3C are identical to 3A, 3B and 3B+.

Execution (Mar 2022)

In a first step, the ATO-GW and the RIU are tested to ensure the correct interfacing to the locomotive. The cabling and the new connectors interfacing the locomotive are also checked.

In Oosterhout, the integration test between GISM and ODS is performed by checking if data can be properly exchanged between them. After securing data exchange, the moving recordings and characterization tests are performed, as described below:

Moving Test:
The moving tests are done by running HLD 77 on the track and approaching obstacles from approximately 200m and the speed of 30km/h.
These tests are done with the driver running the locomotive from the short nose in forward and then in backward direction to test the ODS installed on the short nose and on the long nose.

Characterization Test:
The characterization tests include different scenarios to determine the behaviour of HLD 77 in terms of
1) maximum acceleration
2) maximum deceleration
3) minimum traction force
4) minimum braking force
For this purpose, an ATO simulator is injecting pre-defined commands to the locomotive to measure the reaction. All characterization data is collected and analysed in real-time by ALSTOM.

In addition, the dynamic behaviour of the train driver is monitored and recorded by the ATO-OB during some movements performed for the recording of ODS:
1) starting from standstill
2) stopping to standstill
3) approaching a wagon for coupling.
The aim is to train the ATO to control the train “as a driver” in some situations.

Results

The test session has been performed in March 2022.

The processing of the ODS data enables to confirm the performances from the step 3B+:

- Detection of people: the persons located in gauge, standing or moving, are detected around 300m, with an accuracy of 2m (classification as a human is done around 250m depending on the cases).
- Detection of wagon: the wagon located in gauge is detected around 450m (classification as a wagon is done between 350 and 400m) with an accuracy of 4m.
- Detection of car: the car located in gauge at the crossing is detected around 300m (classification as a car is done between 300m) with an accuracy of 4m.

In all cases, the probability of false positive detection of an object is less than 0,1%. It should be noted that the long nose is equipped with the optic part only from an ODS and the performance are limited e.g. maximum 400m for a wagon.

The outcomes of the test session during this step are globally positive:

- The performances of ODS have been demonstrated in real environment, confirming that it is able to detect the obstacles considered as part of the used cases for this Proof of Concept.
- The NAV system has been successfully integrated with the ATO-OB to provide the speed and location of the locomotive during the characterization tests. The accuracy of the GPS system from the NAV and the reaction time seems sufficient for the Proof of Concept (no ETCS system is available in this locomotive, thus the ATO is relying on GPS for the location and speed information).
- The ATO-GW and RIU have been tested with the locomotive, from these tests, some issues have been highlighted which required an update of the RIU configuration (some misunderstanding of the locomotive drawing about the meaning of some wires in the traction/brake handle were such that the ATO could not control the locomotive correctly). After the correction, the ATO system could control the locomotive, but the time for the characterization was reduced (since they could not start before the RIU issue was solved)
- The characterization tests have been started, unfortunately with limited time since the RIU configuration had to be corrected thus additional tests would be necessary.
- During the performance tests of the ODS, the GISM was also activated, such that it was possible to test for the first time the interface between the ODS and GISM. The two sub-systems would work on-site in a similar way that was tested in laboratory during the weeks before: point position requests are sent by GISM, answered by ODS, and reports of obstacles are sent by ODS to GISM.

Some power supply issues occurred during this test session that led to a modification of the power distribution for the next phase (to avoid complete power failure in the middle of a test).

Phase 3D

Phase 3D is the continuation of Phase 3C in which the ATO-OB controls the train movements. The aim is also to continue the characterisation tests.

Setup

Besides the items mentioned in phase 3C, the following items are present:

1) PAL
2) ATO-TS
3) ATO DMI

The ATO-OB is based on the ATO over ETCS, therefore it requires some information normally provided by an ETCS equipment e.g. Movement Authority information. For this project, there is no ETCS equipment on-board therefore the PAL has to emulate a movement authority towards the ATO-OB. The integration of the PAL, emulating movement authorities, and the ATO-OB has been realized in laboratory and is integrated for the first time during this phase 3D

To automate the train movements in this phase, Journey and Segment Profiles, complying with subset 126, are prepared for different scenarios.

Execution (Jun 2022, Sept 2022)

To begin with, the proper integration between ATO components is tested by ensuring all information for automatic operation are correctly exchanged between the subsystems.
In the next step, for given Journey Profiles, the behaviour of ATO is tested in the following scenarios:

- Clear Track with points in correct position
- Clear track with points in incorrect position
- Obstacles (human, wagon, car) in the gauge
- Obstacles (human, wagon, car) out of the gauge

Finally, the coupling and decoupling scenario is tested: the ATO drives the locomotive to the coupling location, the coupling is done manually. When completed, the ATO runs the locomotive in the opposite direction and stops the locomotive in the decoupling location.

Results

The phase 3D has been executed in 2 steps due to some difficulties in the control of the locomotive by the ATO: as requested by the standardized interface to the ATO-OB, the information of driving direction needs to be received from the locomotive. The HLD77 is implementing a specific traction logic that could not be deduced from the electrical scheme such that the information of direction was no more available on the interface as soon as the ATO tries to control the locomotive. Some adaptations in the RIU logic had to be made to ensure that the driving direction information is available to the ATO-OB. Since some tests were not performed in Oosterhout due to this driving direction issue, a complementary session was made in Antwerp harbour area, where Lineas is operating, to complete this test session.

The completion of Phase 3D brings confidence in the ATO: obstacles and incorrect points are detected & ATO stops the train before them, the traction and braking of the locomotive is smooth, speed limitations are not exceeded, direction is successfully changed.
With regards to stopping points including coupling location, can be accurately reached. However, the traction and braking command of ATO is not precise at very low speeds (stationary).

Phase 4 – PoC

Proof of Concept is the final phase of this project. It intends to demonstrate feasibility of automated shunting. This phase involves a series of activities to test, analyse and improve the performance of the ATO & finally present it to the stakeholders.

Setup

As the ATO system is validated in this step, all subsystems are present:

1) ODS on both sides of the locomotive
2) GISM
3) ATO-GW
4) ATO-OB
5) NAV
6) ATO button box
7) ATO DMI
8) PAL
9) ATO-TS

Execution (Nov 2022)

Prior to on-site testing, lab tests and developments continued within ALSTOM. However, site tests are needed to verify the ATO system. This is mainly due to the limitations associated to controlling the test locomotive. The on-site tests were planned for a week. A series of scenarios were defined and detailed ATO tasks were listed. Each day of the test was dedicated to several tasks.

Table 2 List of Activities for Phase 4

Day	Activity
1	Secure ODS calibration Establish communication between ATO-OB and ATO-TS as well as JP reception
2	Verify automatic driving (traction, braking and accurate stop) Check ATO disengagement
3	Continue with verifying automatic driving Ensure ODS performance
4	Continue with verifying automatic driving Ensure ODS performance
5	Validate coupling (accurate stopping, change of direction)
6	Continue with validating coupling (accurate stopping, change of direction)

Day 1:
The first activity of Day1 is to calibrate the ODS installed on both sides of the locomotive. The environmental conditions could adversely impact the accuracy of the detection. Therefore, it is essential to avoid any false detections during the train movement by properly calibrating the ODS.
Next, it was assured that ATO-OB and ATO-TS could establish a communication session. As no TMS (Traffic Management System) exists, a TRN (Train Running Number) was manually shared with both subsystems.
The ATO-OB sent a HSReq (Handshake Request) to ATO-TS and received HSAck (Handshake Acknowledgement).
The ATO-OB then asked for a Journey Profile (JPReq) and the ATO-TS sent the JP. Afterwards, the ATO-OB was ready to engage and drive the train according to the Journey Profile. The Segment Profiles were already stored in the ATO-OB.

Day 2:
After successfully establishing the communication between ATO-OB and ATO-TS and reception of the JP, the ATO-OB is now able to drive the test locomotive.
The test track was cleared from obstacles and switches were put in their correct position, according to the route defined in the Journey Profile. A stopping point was also defined in the Journey Profile, at the end of track.

This setup allowed to analyse how ATO-OB applies the traction and braking as well as the stopping accuracy. The stopping accuracy was measured by comparing the location of the stopping point against the location where the locomotive stopped.

These tests were repeated several times to assess the consistency and reliability of the stop accuracy.

It was observed that the traction and braking were smooth and close to the driving style of the train driver. However, the desired stop accuracy could not be reached. The contributing factors are lack of odometer information combined with constraints of the locomotive brakes. It was decided to improve this behaviour by modifying the driving library. A new driving library was ready by end of the day.

As the last activity of Day 2, the disengagement of ATO was checked. The disengagement is necessary to be verified as in case of incorrect ATO behaviour, it should no longer be controlling the traction and braking. The disengagement was checked in two ways:

1) Driver applying the brake and ATO disengaging
2) Driver pushing the Emergency button from the ATO button box and ATO disengaging

In both situations, the ATO successfully disengaged.

Day 3 and 4:

Although the traction and braking behaviour of the ATO-OB were in line with the expectations, the expected stopping accuracy could not be reached. ALSTOM tried to improve this behaviour by refining the driving library based on the deviations.

Once the new driving library was received, the tests of Day 2 were repeated. At the end of day 4, the stopping accuracy improved to 5m although the limitations. As the desired stopping accuracy was still not achieved, refinements had to be made to the driving library.

While the refined library was in progress, the performance of the system when facing obstacles was tested by:

1) Putting switches for the given route in incorrect position
2) Putting stitches of the adjacent route in incorrect position
3) Placing obstacles in and out of the gauge:
    - Human
    - Car
    - Wagon

Like the stopping accuracy, these tests were repeated several times to ensure consistency and reliability of the results.

It was observed that the ATO detected correctly which switches belonged to a given route as well as the track gauge. It stopped the train when switches for a given route are in the incorrect position and when obstacles are placed in the gauge. The ATO continued to drive when the switches of the adjacent route were in the incorrect position and obstacles were outside of the gauge.

Day 5:

As the performance of the ATO with respect to obstacle detection was verified, the coupling tests were performed. These tests were carried out on a track with switches in correct position and placing a wagon at the end of the track. The ATO drove the test locomotive to the wagon and stopped. The stopping accuracy was measured and then the coupling was performed manually. Once the driver coupled the wagon and the test locomotive, the ATO changed the driving direction. However, unexpected shut down would occur and ATO was not able to drive in the opposite direction. Further analysis was done in parallel to determine the root cause.

The repeated tests revealed that the stopping accuracy was improved to 2m at this point. As this value was still higher than desired, the driving library had to be improved.

While changes were made to the driving library, another series of obstacle detection tests were carried out. Like the previous day, obstacles were placed in the gauge and switches for the given route were put in the incorrect position. After ATO stopped the test locomotive in front of the obstacle or incorrect switch position, the obstacles were removed, or the switches were put back in the correct position. The ATO successfully detected that it was safe to proceed and resumed driving the locomotive.

Day 6:

Day 6 was the last day of testing before the final demonstration. The latest version of the driving library was integrated into the ATO-OB. ALSTOM also managed to determine the root cause of sudden shut-down of ATO during change of direction and resolved it. The coupling scenario, performed on Day 5, was repeated this day.

The ATO drove the test locomotive to the wagon and stopped just before it. After coupling was performed, it changed the direction and drove the test locomotive in the other direction. The ATO finally stopped the train in the decoupling location.

After several repetition, the stopping accuracy was confirmed to be less than 1m. The ATO successfully stopped the loco in a way that only manual coupling was left to be performed. The change of direction also took place with no issue.

Final demonstration

After the last day of testing, a final demonstration was arranged to demonstrate automatic shunting to the stakeholders.

Setup

The setup for this phase is identical to the last step.
ALSTOM opted several external screens and connected them to the ATO-DMI. This is to provide stakeholders, placed in a separate location, with the information of the ATO-DMI and from the ODS System.

Figure 23 DMI in the locomotive

Figure 24 External screen

Execution (Nov 2022)

The final demonstration scenario included:

1) ATO driving a train to a crossing switch in wrong direction
   The ATO started driving the test locomotive. The crossing switch was put in the incorrect position. The ATO detected that for the give route, the crossing switch is in the wrong position and stopped the locomotive at a configured distance before it. The configured distance is 20m.
2) ATO continuing the movement after the switch is put back in the correct position
   When the test locomotive was stopped, the crossing switch was manually put in the correct position. The ATO detected that the switch is in the correct position and started applying traction again.
3) ATO stopping before a car and starting when the car is removed
   A car was placed in the gauge of the track where the test locomotive was running. The ATO detected and classified this obstacle and stopped at the configured distance before it. After the test locomotive was no longer moving, the car was removed. The ATO started driving the test locomotive again.
4) ATO driving the train again stopping before a human standing in the gauge
   Like the previous scenario, a human was placed in the gauge. The ATO detected and classified the obstacle and stopped the test locomotive at the configured distance before it.
   The ODS was even able to detect and classify the human obstacle in adverse weather condition, fog. The precision of the detection was not changed compared to the previous findings.

Figure 25 ATO stopping the locomotive before human

Figure 26 ATO stopping the locomotive before human during foggy conditions

5) ATO again resuming after the person walked out of the gauge
The human obstacle moved to the side of the track. The ATO resumed and continued to run the test locomotive.
6) ATO stopping right before a wagon and the driver performing manual coupling
A wagon was placed on the track. The ATO detected and classified the wagon. It approached the wagon and stopped right before the wagon. The driver then coupled the wagon and the locomotive.

Figure 27 ATO stopping accuracy for coupling

7) ATO changing the driving direction and driving in the other location, stopping at a stopping point
Once the coupling was completed, and the “coupling confirmed” button on the ATO button box was pushed, the ATO changed the travelling direction and drove the train in the opposite direction until the end of journey was reached.

Results

The results of the final phase are summarized below:

1) The proposed architecture described in §0 is validated. Automatic shunting in such a complex environment with no ATP and using an old freight train was achieved successfully.
2) The ODS detected, classified and reported obstacles and switch positions within a given route. Even though detecting diamond switches first appeared to be challenging, with sufficient training such switches could be detected. The ODS is able to:
    - Detect people: human located in gauge, standing or moving, are detected around 300m (classification as a human is done around 250m depending on the cases).
    - Detect wagon: the wagon located in gauge is detected around 450m (classification as a wagon is done between 350 and 400m).
    - Detect car: the car located in gauge at the crossing is detected around 300m (classification as a car is done between 300m).
    - Detect switches: the switches and their position are detected between 150-120m.
3) The developed driving library was advance enough. It not only overcame the inaccuracy challenges due to train braking system limits and no odometer data but stopping accuracy below 1m was achieved. In the coupling scenario, when the ATO stopped the train, there was no gap between the test locomotive and the wagon. In addition, the driving style of the ATO was similar to the train driver: the traction and braking were smooth and there was no sudden and aggressive braking nor acceleration.