AUTOMATIC TRAIN OPERATION

DRIVING THE FUTURE OF RAIL TRANSPORT

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TNO innovation for life

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EXECUTIVE SUMMARY

How does one of the world's densest and busiest rail infrastructure systems address the increasing need for capacity and competitiveness? By exploring the opportunities to enhance the current system with new technology. Automatic Train Operation (ATO) is a promising innovation with various levels of automation, ranging from train driver support to unattended train operation. When fully implemented, ATO trains operate automatically and no interference of a driver is needed. Companies in the rail and transport sector can benefit from ATO in a number of ways. This includes improved capacity usage, lower energy consumption and improved punctuality. What's more, society benefits from the potentially safer, more efficient and more sustainable solution.

ProRail, the Dutch Rail Infrastructure Management organisation, asked TNO to objectively explore the potential of Automatic Train Operation. We start by explaining what ATO is and why it could be implemented in rail transport. Next, we describe the development path that can be distinguished, including a description of current projects and initiatives both in the Netherlands and around the world.

Wide-scale deployment of ATO does come with challenges. It is a system-wide innovation that involves many different stakeholders. As such, we explore the varying objectives and roles of the different stakeholders involved (developers, users, logistics parties, policymakers, regulators and society). Subsequently, a high-level value case is proposed, including scenarios for passenger transport, shunting and long-haul transport. Finally, we conclude by identifying the conditions needed to succeed in implementing ATO as the promising innovation in rail transport.

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1. AUTOMATIC TRAIN OPERATION

IMPROVING RAIL TRANSPORTATION

Photo: ProRail/ Stefan Verkerk

Imagine a train that operates without human intervention. It opens and closes its doors automatically. It starts and stops driving at the right location automatically. And it fully controls the train in case of disruptions. The train chooses the optimal speed profile and braking scheme, and is always 100% aware of what happens within and in front of it, so that it is able to react immediately if necessary.

Admittedly, this is an advanced scenario that represents the highest level of ATO (Automated Train Operation), which might be years away. However, ATO can also be seen as a system that supports the train driver in executing tasks, or even takes over some of the driver's tasks entirely (see 1.2 Automatic Train Operation; Box 1). In various countries, initiatives have begun to enable the first phases of ATO, which will support the human driver. Depending on the partners involved in these initiatives, the ultimate ambition is to realise the advanced scenario described above.

ATO SUPPORTS THE TRAIN DRIVER IN EXECUTING ITS TASKS OR EVEN TAKES OVER SOME OF THE DRIVER'S TASKS

ATO involves system-wide innovation. It is therefore important to combine forces with all relevant stakeholders, like Railway Undertakings, Infrastructure Managers, industry, science, government and residents. This white paper is a first step, in which ProRail asked TNO to objectively explore the potential of Automatic Train Operation.

Chapter 1 describes ATO and why we are in need of this innovation in the rail sector. Chapter 2 explores the future of rail transportation by analysing the Dutch ATO pilots that are planned in 2018, as well as several international developments. In Chapter 3, we consider all relevant stakeholders and the possible impact of ATO. Subsequently, in Chapter 4, we explore the value of ATO in more detail using three different value scenarios. Finally, we conclude in Chapter 5 by presenting the conditions needed to succeed.

1.1 THE DRIVE FOR CHANGE

The grand capacity challenge

In rail passenger transport, the question is how to facilitate the growing passenger volumes now and in the future. In the Netherlands, national capacity analysis shows that passenger movements (kilometers) by train are projected to grow 25-45% between 2014 and 2040 (Ministery of Infrastructure and the Environment, 2017). Since the existing infrastructure in the Netherlands will not grow as much as needed, we must further optimise the use of the existing means of transport (car, truck or train) to support growing passenger volumes.

Also, bottlenecks are expected on the freight rail corridors to, amongst others, Germany (Ministery of Infrastructure and the Environment, 2017). For rail transport, the capacity study predicts that by 2040, the most preferred corridors for shipment will face serious capacity constraints.

ATO has the potential to optimise the use of the existing infrastructure, as we show in section 1.3 and in Chapter 4 more elaborately.

Competitiveness of rail transport

In addition to the capacity challenge, we also observe that other transport modes are gaining in competitive force when compared to rail transport. Developments in transport automation are progressing quickly, as these have great potential benefits for more sustainable, smarter and safer transport (see Figure 1 and Box 2).

European Truck Platooning Challenge (OEM Off Highway, 2016)

Smart shipping Challenge (SSC, 2017)

North East Line Singapore (Singapore Business Review, 2012)

What about automation in rail transport? (Idfi, 2015)

Figure 1 *- Developments automation in transport*

In the metro and aviation industry, automation has already been developed and applied for a long time (see Box 2). For instance, the first fully automated (driverless) metro was launched in Singapore as early as 2003 (Land Transport Authority, 2015). And today, there is autonomous operation in almost 40% of the metro systems worldwide (Shift2Rail, sd). In addition, the autopilot functionality has been used for many years in the airline industry.

For other modes of transport, development of automation opportunities has taken place in the last couple of years. For road transport, self-driving cars and truck platooning are experiencing on-going development. In 2016, the European Truck Platooning Challenge (ETPC) was organised. The ETPC is a large-scale experiment in which platoon-driving technology (trucks driving in a road train, see Janssen et al., 2015) was tested in real-life conditions. Also, more and more attention is being given to autonomous shipping in barge transport. The Smart Shipping Challenge 2017 (SSC) demonstrated that inland vessels could operate autonomously. In barge transport, the technical possibilities of autonomous sailing have already been proven, as they have for autonomous road transport.

In addition, studies (Shift2Rail, sd) have shown the advantages of preparing the required legislative modifications, analysing the human-machine relationship and developing multi-brand solutions for autonomous driving and sailing. These studies aim to prepare for and accelerate the implementation of autonomous driving and sailing.

In these recent developments, there is one important modality missing. To what extent is rail transport automatic and autonomous? Many people expect rail transport to be one of the first modes of transport to be automated, since a train can only drive forward or backward on the track. Unfortunately, this is not the case. Section 1.1.1 describes the challenging conditions of the Dutch rail sector.

To conclude this drive for change, there is great urgency for the rail sector to keep on innovating in order to cope with the grand capacity challenge and improve the competitiveness of rail. The rail sector is keen to do so in order to be prepared for the future. The technological possibilities offered by automating rail transport through ATO might bring about this needed innovation, as we will show throughout this whitepaper.

IN THESE RECENT DEVELOPMENTS THERE IS ONE IMPORTANT MODALITY MISSING: TO WHAT EXTENT IS RAIL TRANSPORT AUTOMATIC AND AUTONOMOUS?

1.1.1 Challenging conditions

In the Netherlands, the rail infrastructure is one of most utilised in the world, and has a high density of railway junctions. Furthermore, freight trains and passenger trains are mixed on 80% of the Dutch railway infrastructure. Also, the dynamic timetable that is used increases the level of complexity compared to static timetables. Therefore, international ATO initiatives cannot simply be implemented in the Netherlands, as the conditions are different.

In 2018, the Dutch government is planning to alter legislation in a way that makes autonomous driving on the Dutch road infrastructure possible. Minister Cora van Nieuwenhuizen (Raad van State, 2017) wants to set up a framework to permit experiments on the Dutch road infrastructure with, among other things, reliability and safety requirements for autonomous driving. This is a crucial step in the advancement and use of this emerging technology and spread to other mobilities like Rail. Our developments of the technology should remain in line with changing legislation and social expectations.

1.2 AUTOMATIC TRAIN OPERATION

Automatic Train Operation (ATO) is a system that supports the train driver or even takes over some of the driver's specific tasks, depending on the degree of automation (ProRail, 2018). ATO is more than 'automatic driving': the system also provides opportunities to realise an optimal speed profile with respect to energy efficiency, punctuality and safety. In addition, bidirectional train-to-wayside communication is needed to provide ATO with real-time updates of infrastructure and train data, such as conditions and train position (Schaafsma, 2018).

Using the Grades of Automation (GoAs) developed for metro systems, the implications for ATO can be illustrated (see Figure 3). ATO's full potential is achieved at GoA 4. In this scenario, setting the train in motion, stopping the train, closing the doors and operation in event of disruptions are performed automatically. This is also referred to as UTO (Unattended Train Operation).

Grade of Automation	Type of train operation	Setting the train in motion	Stopping train	Door closure	Operation in event of disruption
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 2	Semi-Automated Train Operation	Automatic	Automatic	Driver	Driver
GoA 3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA 4	Fully automated / Unattended Train Operation (UTO)	Automatic	Automatic	Automatic	Automatic

Automatic Train Protection (ATP) is the system and all equipment responsible for basic safety; it avoids collisions, red signal overrunning and exceeding speed limits by applying brakes automatically. A line equipped with ATP corresponds (at least) to a GoA 1.

Figure 2 - Grade of Automation (UITP, 2012)

Technological advancements now allow train control systems to supervise, operate and control the entire operational process. The extent to which they do so can be defined as:

- Semi-Automatic Train Operation (semi-ATO): partial or complete automatic train piloting and driverless functionalities. The ATO system performs all the driver's functions, except for door closure and operation in the event of a disruption. The driver continues to perform these two functions. If the way is clear, the train will automatically proceed to the next station. This corresponds to GoA 2, which will deliver the biggest impact on the daily rail operations and infrastructure management, because rails will potentially be safer and energy consumption, track capacity and punctuality can be optimised.
- Driverless: Although many newer systems are completely controlled by computers, most systems still involve a driver, or a train attendant of some kind, to mitigate risks associated with failures or emergencies. Several sensors on the train that react to obstacles on or around the track increase safety and decrease disruptions. This corresponds to GoA 3.
- Unattended Train Operation (UTO): automatic performance of normal signaller operations, such as route-setting and train regulation. The ATO and the Automatic Train Control (ATC) systems (see Box 1) work together to ensure the train remains within a defined tolerance of its timetable. The combined system will marginally adjust operating parameters, such as the ratio of power to coast and station dwell time, in order to bring the train back to the timetable slot defined for it. There is no driver, and no staff assigned to accompany the train, corresponding to GoA 4.

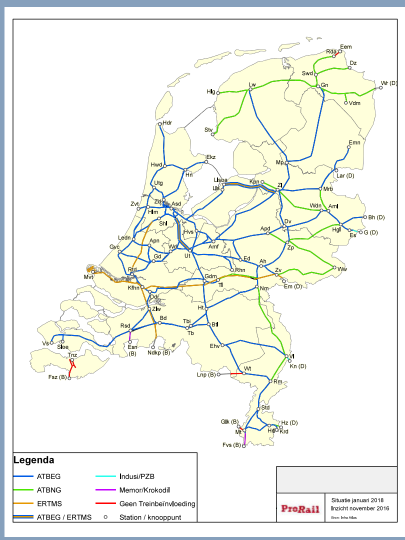
BOX 1 –DUTCH RAILWAY PROTECTION TECHNOLOGY – NOW AND IN THE FUTURE

In the Netherlands, there are currently several ATP systems in place, operating on GoA 1. The main systems are ATB (several versions in operation, see map 1) and ERTMS. The driver performs all traction and braking of the train, within the safety parameters set in the ATP system.

ATB – AUTOMATIC TRAIN CONTROL

ATB (*Automatische Trein Beïnvloeding* (in Dutch) / Automatic Train Control) is a Dutch train protection system developed in the 1950s.
Its installation was spurred by the Harmelen train disaster of 1962. With ATB, the train collects electrical signals from line-side apparatus and will override the driver's controls in the following situations:

- failure to reduce speed at a caution signal (ATB will slow the train sufficiently to stop at the next signal),
- failure to observe speed limits (ATB makes an immediate emergency brake application).



Speed limits are set at five levels: 40 km/h, 60 km/h, 80 km/h, 130 km/h and the so-called *volle materieelsnelheid* (i.e., full speed allowed for that type of train), which can be 140 km/h at most for non-high-speed trains. If the train's maximum allowed speed is lower, the 130 km/h setting is omitted.

EUROPEAN RAIL TRAFFIC MANAGEMENT SYSTEM - ERTMS

The European Rail Traffic Management System (ERTMS) is the European Union (EU) system of standards for management and interoperation of signalling for railways. It is conducted by the European Union Agency for Railways (ERA) and is the organisational umbrella for the separately managed parts of:

- GSM–R (communication),
- European Train Control System (ETCS, signalling),
- European Train Management Layer (ETML, payload management)

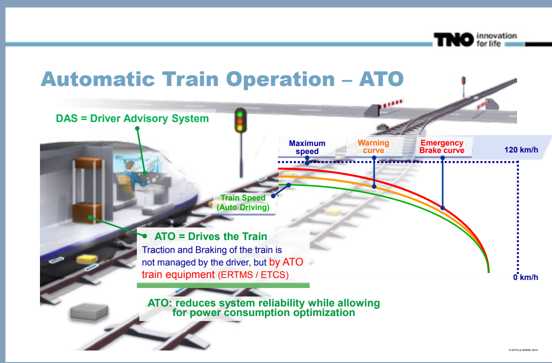
The main target of ERTMS is to promote the interoperability of trains in the EU. It aims to greatly enhance safety, increase efficiency of train transports and enhance cross-border interoperability of rail transport in Europe. It includes the replacement of former national signalling equipment (link ATB in the Netherlands) and operational procedures with a single, new Europe-wide standard for train control and command systems.

The yellow beacons in the rail are ERTMS-beacons (eurobalises). When a train with ERTMS on board passes the ERTMS beacons, the ERTMS system is activated and will signal to the train control system, such as ETCS.

EUROPEAN TRAIN CONTROL SYSTEM – ETCS
ETCS is implemented with standard track-side equipment and unified controlling equipment within the train cab. In its advanced form, all line-side information is passed to the driver's wireless inside the cab, eliminating the need for drivers to watch the line-side signals. This provides a foundation for Automatic Train Operation (ATO), to be defined at a later time.

The DMI (Driver-Machine Interface) will display all driver-relevant information, such as current speed and current distance to the train in front of it, and whether these are within the allowed boundaries. If not, the train will automatically slow to a safe speed and distance.

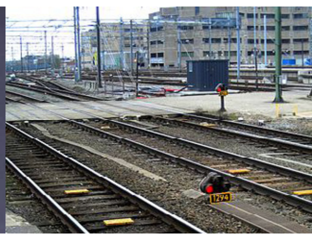
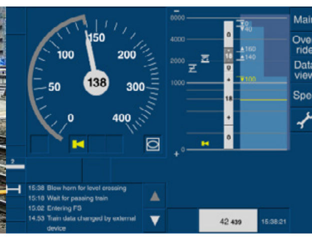
AUTOMATIC TRAIN OPERATION - ATO
ATO is an operational enhancement device used to help automate train operations. Mainly, it is used on automated guideway transits and rapid transit systems, on which human safety is more easily assured. Most systems elect to maintain a driver (train operator) to mitigate risks associated with failures or emergencies.



To reach the next GoA, an ATO system has to be connected to the ATP system of the train. Furthermore, the ATO system has to be linked to the Train Management System (TMS). In the Netherlands, the ATO system will be connected to the ATB or the ETCS system of the train.

RAIL INNOVATION COMMUNITIES
In Europe, there are several communities involved in rail innovation. The most important in relation to ATO are:

- European Union Agency for Railways (ERA): the EU agency that sets mandatory requirements for European railways and manufacturers in the form of Technical Specifications for Interoperability (TSIs), which apply to the Trans-European Rail system. http://www.era.europa.eu/
- RailNetEurope (RNE): a non-profit association whose aim is to enable fast and easy access to the European rail network, as well as to increase the quality and efficiency of international rail traffic. RailNetEurope currently counts 37 members, all of whom are rail Infrastructure Managers and/or Allocation Bodies, with a combined rail network totalling well over 230,000 km across Europe. www.RNE.eu
- UIC (Union Internationale des Chemins de fer) or International Union of Railways: an international rail transport industry body. The UIC's mission is "to promote rail transport at world level and meet the challenges of mobility and sustainable development." www.uic.org
- Shift2Rail: the first European rail initiative to seek focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. Shift2Rail promotes the competitiveness of the European rail industry and meets changing EU transport needs. R&I carried out under this Horizon 2020 initiative develops the necessary technology to complete the Single European Railway Area (SERA). www.shift2rail.org


ATO YIELDS GREAT POTENTIAL BENEFITS: CAPACITY OPTIMISATION, ENERGY CONSUMPTION OPTIMISATION AND IMPROVED SERVICE QUALITY – INCLUDING PUNCTUALITY.

1.3 WHY AUTOMATIC TRAIN OPERATION?

Depending on the Grade of Automation, ATO can offer various benefits. The benefits described are expected based on observed effects in metro automation and ATO trials in the railway sector (e.g. Thameslink London).

From GoA 2 onwards, ATO is able to calculate the most optimal driving curve and controls traction and braking. As a result, it will be possible to increase the capacity utilisation of the rail infrastructure. Also, ATO will minimise energy consumption, leading to a reduction in CO_2 emissions. ATO also contributes to higher service levels by improving punctuality.

These are only some of the potential benefits of ATO. In Chapter 4, we explore them – and other advantages – in more detail. These benefits are assigned to different stakeholder groups and scenarios. In the next chapter, we provide a glimpse into the future by exploring national and international ATO developments.

BOX 2 - AUTOMATED TRANSPORT TECHNOLOGY IN VARIOUS TRANSPORT MODES

METRO AUTOMATION

In metro systems, automation refers to the process by which responsibility for operation management of the trains is transferred from the driver to the train control system (Metro automation, 2016). The technological systems that make metro automation possible are: Automatic Train Protection (ATP), Automatic Train Operation (ATO) and Automatic Train Control (ATC). ATP serves as the safety system, ATO ensures partial or complete automatic train piloting and ATC automatically performs signaller operations, such as route-setting.

Advantages - Fully automated metro systems (Unattended Train Operations) lead to optimisation of train running times, increased average speed, headways shortened by up to 75 seconds and dwell time at stations reduced by 15 seconds in optimal conditions.

AIRLINE AUTOMATION

In the airline industry, 'autopilot' technology has been around for quite a while. The Flight Management System (FMS) is a specialised computer system that automates various in-flight tasks (KLM, 2015). The FMS consists of three systems: Flight Management Computer, Auto Flight System, and Inertial Reference System. Together, these systems control the speed, altitude and routing of the plane (three-dimensional navigation, including a time constraint). After take-off, once the plane is above 400 feet, the pilot can choose to switch on the autopilot. The autopilot controls flight until landing. The pilot is responsible for entering the proper data inputs into the system and takes over if the autopilot unexpectedly fails.

Advantages - The FMS improves navigation, optimises fuel efficiency, reduces the workload of the crew-members (which is especially important on long-distance flights) and improves accuracy (Londhe, 2015).

TRUCK PLATOONING

When trucks are platooning, they drive very closely behind one another (see Figure 3), which is possible with automated driving technology and wireless vehicle-to-vehicle (V2V) communication. Other technologies that are required for truck platooning are: Advanced Driver Assistance Systems (ADAS), Advanced Emergency Braking (AEB) and Lane-Keeping Assist (LKA).

Advantages – Truck platooning results in improved driver productivity and fuel savings (between 4% and 16%). Extensive use of ADAS can improve traffic safety. Lastly, the fuel savings have a one-to-one relationship to CO_2 emission reduction. Whether truck platooning has a positive impact on accessibility and traffic flow has not yet been proven (Van Ark et al., 2017).

AUTONOMOUS CARS AND SELF-DRIVING CAR TECHNOLOGY

SAE international has developed a system to determine the levels of automation in cars. When an automated driving system undertakes all aspects of dynamic driving throughout a drive, SAE level 5 (or full automation) is achieved (Heineke, sd). Self-driving cars rely on numerous sensors, such as: ultrasonic sensors (e.g. for park assist), radar and lidar for detecting speed and distance of objects, Dedicated Short Range Communication (DSRC) for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, Inertial Navigation Systems (INS) combined with GPS for vehicle orientation and speed estimation, and cameras and infrared sensors.
In addition, the autonomous driving system consists of –amongst others – the following elements: actuation (steering, braking), perception and object analysis, localisation, mapping and drive control (Heineke, sd).

Advantages – Improved safety, traffic flow and fuel efficiency.

SMART AND AUTONOMOUS SHIPPING

Smart shipping encompasses the developments that increase the level of intelligence on vessels and at the shoreline, such as remote-controlled ships, information sharing, waterway maintenance optimisation or (partially) autonomous shipping (Smart shipping challenge, sd). Several tasks of the primary shipping process can be (partially) transferred to automation systems, including loading, unloading and sailing the ship (Jongeling, 2017).

Advantages – Improved efficiency, safety and sustainability of shipping industry. Furthermore in the case of more autonomous shipping, the captain's workload will be reduced (Smart shipping challenge, sd) and fewer crewmembers will be required. This last point is considered especially relevant for dirty, dangerous and dull jobs.

COMPARISON ACROSS MODES

In Table 1, technological maturity (low-medium-high), business life cycle (infancy-expansion-maturity) and user (i.e. driver) and societal acceptance (unknown-low-medium-high) are compared. This is a rough estimate to indicate that automation in the rail sector is still in its infancy, when compared to other transport modes. In Chapter 2, we elaborate on the developments in ATO as it begins to grow around the world. In the Netherlands, ATO is rather challenging due to the high density of railway junctions. Furthermore, freight trains and passenger trains are mixed on the Dutch railway infrastructure.

	Technological maturity	Business life cycle | deployment	User acceptance	Societal acceptance
Metro	High	Expansion | yes	High	High
Airline	High	Maturity | yes widespread	High	High
Truck platooning	Medium	Infancy | pilots only	Medium	Unknown
Autonomous cars	Medium	Infancy | pilots only	Low	Low
Smart shipping	Medium	Infancy | pilots only	Medium	Medium
Train	Low	Infancy-Expansion| see Chapter 2	Unknown	Unknown

Table 1 - Comparison of automated technology maturity across transport modes. This comparison is based on global developments.

WHAT CAN THE RAIL INDUSTRY LEARN FROM THESE TECHNOLOGIES?

Two lessons can be learned from the automated transport examples above. First, there is a range of knowledge and technologies already available in other transport sectors that prove that automated transport is possible and yields a variety of benefits. These benefits boil down to making transport safer, more efficient and more sustainable. Second, these automated technologies show that human-machine interaction is very important. Successful implementation of these technologies illustrates that humans are able to transfer (some of their) control over to automated systems.

Photo: RRF

2. A GLIMPSE INTO THE FUTURE

Photo: ProRail/ Stefan Verkerk

The Dutch rail infrastructure is one of the busiest and densest in the world. It connects all major towns and cities. The network totals 3,223 route kilometres (6,830 km of track, for movement in both directions, or multiple lines running in the same direction). The Dutch network is heavily focused on passenger rail services. Most freight routes run east/west, connecting the Port of Rotterdam and the blast furnaces in IJmuiden with Germany. Freight trains usually share the tracks with passenger trains. The only exception is the Betuweroute, which opened in 2007 as the first freight-only route in the Netherlands.

Infrastructure Manager ProRail is responsible for keeping the trains on schedule. It also takes charge of safety, management and maintenance of the rail infrastructure. Given the network's busy, dense nature, ProRail and Railway Undertakings (RUs) must maintain close contact with each other. Only then can they keep the punctuality at stations above the norm of 88,9% within 3 minutes of the scheduled arrival or departure.

Further innovation and automatisation, such as ATO, will help to get more trains on the tracks and maintain or increase punctuality. Before an innovation like ATO can be implemented, ProRail and the RUs will perform trials in selected areas to test the new technology intensively and ensure that it is safe to use.

In this chapter, we explore the Dutch trials in more detail. We also highlight some interesting international developments that provide us with a glimpse into the future of ATO. We conclude with a general timeline of ATO development stages.

2.1 ATO REAL-LIFE TESTING IN THE NETHERLANDS

ProRail plans to start trials with ATO GoA 2 in 2018 and 2019. This implies that ATO will support the train driver in setting the train in motion and stopping it. One of the trials will be on the Betuweroute freight line between the Port of Rotterdam and Valburg, near the German border. The other trial will be held with passenger trains in the Province of Groningen, in the north of the Netherlands, on non-electrified regional lines operated by Arriva Nederland. The latter will be the first test of ATO in passenger traffic on conventional lines that include level crossings.

ProRail and the Dutch infrastructure supervisor IL&T (*Inspectie Leefomgeving en Transport*) will work closely together to discover how ATO can be tested and implemented in a safe way. Before ProRail can start with the trials, IL&T must give their approval (use exemption). As mentioned in section 1.1.1, a legal framework that permits ATO experiments on Dutch rail infrastructure will speed up the adoption of ATO. With the trials, ProRail and the involved RUs want to prove that ATO will deliver more capacity on track, less energy consumption and more punctuality in the timetable. The trials will also provide more clarity about the role of the driver in a GoA 2 scenario.

WITH THE TRIALS, PRORAIL AND THE INVOLVED RAILWAY UNDERTAKINGS WANT TO PROVE THAT ATO WILL DELIVER MORE CAPACITY ON TRACK, LESS ENERGY CONSUMPTION AND MORE PUNCTUALITY

2.1.1 The freight line trial

The Betuweroute trial will be conducted with Railway Undertaking Rotterdam Rail Feeding (RRF) and rolling stock manufacturer and railway solutions provider Alstom. The plan is to perform the trial at the end of 2018. In the meantime, the RRF locomotive will be adjusted to fit the ATO GoA 2 system from Alstom. It will be tested in a safe setting without any risks to other rail transport or the environment. Upon successful completion of the testing, the real trial will begin. A number of consecutive free paths will be reserved, so that several real-time test scenarios can be conducted, both with ATO and without ATO.

The scenarios will focus on autonomous braking, acceleration and simulated incidents. Results will be compared to non-autonomous driving and driver reaction to the trials will be measured. Trial testing will take place on the ERTMS level 1 and 2 track and also in an advanced simulator.

Photo: ProRail/Stefan Verkerk

ProRail aims to perform the trials within a two-week timeframe.

2.1.2 The passenger line trial
The Groningen passenger line trial will be done together with RU Arriva. The ATO supplier is not yet known. The trial will begin at the end of 2018 and will continue in 2019. The trial will be conducted at night, due to the fact that passenger line in Groningen is very busy in the daytime. The test will also be performed in a two-week timeframe, with nearly the same scenarios as the freight trial. Special attention is reserved for testing around level crossings. The trial will take place in the province of Groningen on an ATB track (see Box 1). This will be the first test with an ATO GoA 2 system on an ATB track. As described in Box 1, 75% of the Dutch rail infrastructure network works with the ATB-NG (New Generation).

2.2 INTERNATIONAL DEVELOPMENTS AND INITIATIVES
Several countries are testing, demonstrating and implementing ATO. Below, we highlight several European cases and one Australian case that are deemed particularly interesting and show us the developments towards ATO. Table 2 shows the overview of present and future developments for the initiatives discussed below.

	GoA 1	GoA 2	GoA 3	GoA 4
Present	The Netherlands	– Czech Republic (1990s) – Denmark: S-bahn Copenhagen (2016) – Belgium: tests Bertrix Virton & Brussels- Leuven (2017) – United Kingdom: Thameslink London (2018) – France: Paris – Lyon (2018)		Rio Tinto, Australia (2017)
Future		– The Netherlands: Betuweroute trial; Groningen trial (2018) – United Kingdom: London Crossrail GoA 2 over CBTC[1] (2018); London Birmingham (2026) – Switzerland (2038) – Germany: S-Bahn Hamburg (2021)	United Kingdom: London Crossrail shunting (2018); Thameslink (2020)	– Thameslink (2020) – France (2022) – Denmark: S-bahn Copenhagen (2030) – Germany: Hamburg-Bergedorf shunting (2021)

Table 2 - Present and future developments: GoAs

1 CBTC = Communications-Based Train Control, a railway signalling system that makes use of telecommunications between train and track equipment for traffic management.

Czech Republic – AZD Praha

Period
1990s-present

GoA
2

Scope
ATO covers 2,955 km ~ 30% of CZ railway network

Results
Just-in-time arrival accuracy +/- 5 sec; energy savings 10-30%; significant CO_2 reduction

Future deployment
ATO with ETCS
Dynamic information for ATO

2.2.1 Czech Republic[2]

In the Czech Republic, ATO has been in regular operation for 25 years. The pilot installations of full (analogue) ATO were tested in commercial operation. From the early 1990s onwards, new trains[3] were equipped with fully digital ATO (GoA 2). The automation system that is applied is designed for railway and metro application. ATO controls traction engines and brakes (traction, dynamic, pneumatic). It is interesting to note that the Czech ATO system functions with different ATP systems.

Current system and future deployment

Currently, the Czechs (AZD Praha) are working on combining ATO with the European Train Control System (ETCS). This is seen as an ideal combination for safe, effective, exact and comfortable train operation. ETCS will be the safety layer and will provide on-track orientation instead of the ATO balises. ETCS provides the speed profile. ATO is the automation layer and provides interface functions for service braking. By combining ATO with ETCS, the driver's workload will decrease significantly.

ATO over ETCS will be implemented when on-board ETCS is installed for vehicles on which ATO is in operation.
In addition, dynamic information for ATO is one of the future deployment activities. This concerns implementing actual traffic information and actual route map information. AZD Praha participates in the European project Shift2Rail, which includes an ATO technology demonstrator in order to ensure European standardisation and interoperability.

United Kingdom – Thameslink

Period
2018-present

GoA
2

Scope
Thameslink: 7 km. in the core of London (part of the Bedford-Brighton service)

Results
High-intensity train service (Expected result: 24 trains/h each way, offering 70% more seats through the centre of London)

Future deployment
GoA
3/4 bench and line demonstrations towards +/- 2022

2.2.2 United Kingdom – Thameslink[4]

In 2011, Govia Thameslink Railway (GTR), Network Rail and Siemens announced the introduction of ATO on their core section, using ETCS. One of the main reasons for introducing ATO was the doubling of the number of passengers since 1996 and a projected doubling in the next 25 years. A system upgrade to digital and the enablement of conventional works are considered to address the challenge of the strong need for more capacity.

In March 2018, GTR, Network Rail and Siemens succeeded with the ambitious goals they set in 2011.
They are the first to commercially use ATO over ETCS (Briginshaw, 2018). The ambitions are astonishing, as Thameslink is going to be able to deliver up to 24 trains per hour each way, with 70% more seats through the centre of London.

Current system and future deployment

In Thameslink, ATO GoA 2 has been adopted, which means that ATO automatically stops and accelerates the trains. The driver checks the platforms, closes the doors and initiates departure from each station (Spoorpro, 2018). Furthermore, ATO calculates a braking curve, but also sees the protection curve that ETCS is calculating. A shore-based system called Automatic Train Regulation (ATR) holds the geographic route map of the core and the base timetable and, for each train, automatically updates both dwell time and run time to next station (Bickell, 2018). Public mobile or WiFi connections are used for communication. Updated journey information is sent to the driver on the move at any time (Bickell, 2018). Future deployment is focused on operationalising GoA 3 and 4.

2 Information is retrieved from AZD Praha presentation in the EU Agency for Railways ATO workshop (December 2016).
3 Electric Multiple Units (EMUs)
4 Information is retrieved from Network Rail presentation in the EU Agency for Railways ATO workshop (December 2016) unless stated otherwise.

Switzerland - SBB

Period
2017 - 2038

GoA
2 (> 2022); 3/4 (> 2027)

Scope
Standard for Switzerland

Results
Not yet

Future deployment
All vehicles equipped with ETCS by 2025 and ATO in 2038

2.2.3 Switzerland

In 2017, the Swiss SBB launched a comprehensive digitisation program called SmartRail 4.0. This program should make it possible for SBB to adapt to the growing mobility market in Switzerland. It is predicted that by 2030, 51% more passengers (Pkm) will take the train and 45% more freight (Tkm) will be carried by train.
Switzerland (as non-EU member) is the first country with a fully ERTMS-compatible (L2/L1LS) network. All vehicles will be equipped with ETCS by 2025, and with ATO by 2038.

SBB is testing ATO on its own network. On the main network, GoA 2 will be used and GoA 4 is the aim for shunting. The architecture is based on TSI (Technical Specifications for Interoperability) with a clear split between ETCS and ATO. The goal is to have ATO GoA 2 ready for use in 2022 (see Figure 3).

France – SNCF

Period
2018-2022

GoA
2 and 4

Scope
Paris – Lyon (GoA 2, 2018) & Main lines (GoA 4, 2022/2023)

Results
Not yet

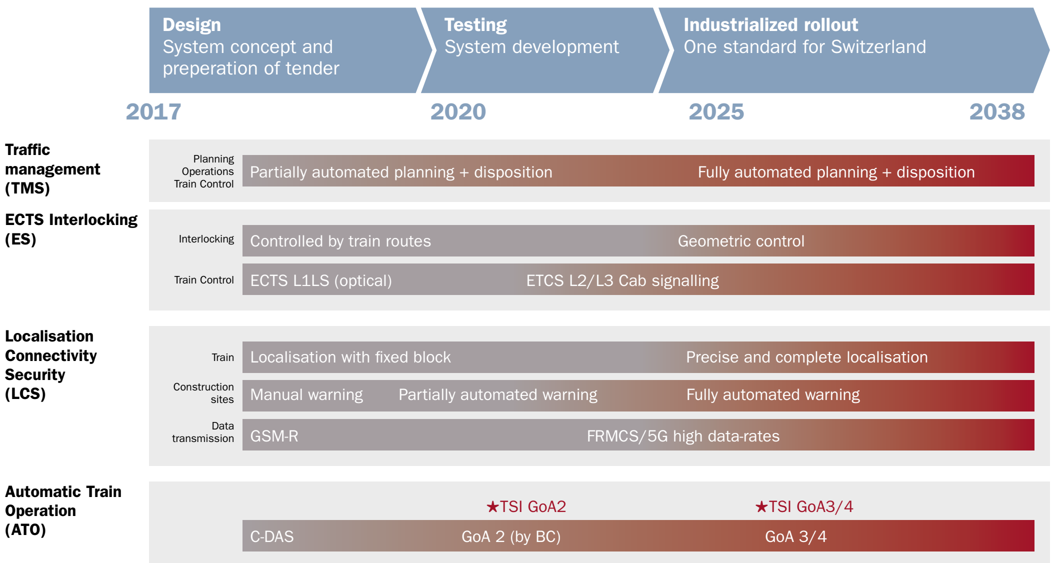
Future deployment
GoA 4 in 2022

2.2.4 France

The French national railway company SNCF's goal is to carry more passengers and goods over its network and improve services at the same time. Therefore, SNCF aims to run high-speed automated trains by 2023 (Railway Pro, 2017). This will increase efficiency and speed. The number of trains on the Paris-Lyon line can be increased by 25% (Global Rail News, 2017).

In 2018, a project began to initiate ATO GoA 2 over ETCS to increase capacity on the Paris-Lyon high-speed line. An initial prototype of the technology will be built in 2020, followed by a second version in 2022 (Laroche, 2017). SNCF main line trials with ATO GoA 4 prototypes for freight and passenger applications will be performed in 2022. This will be done in a partnership with, amongst others, DB (Deutsche Bahn).

Figure 3 - ATO developments SBB (Intelligent Rail Summit 2017)



Belgium - NMBS

Period
2017

GoA
2

Scope
Tests Bertrix-Virton and Brussels-Leuven (2017)

Results
Improved capacity, reduction of energy consumption (Alstom)

Future deployment
Focus on improving capacity

2.2.5 Belgium - NMBS

The Belgian national railway company NMBS is exploring whether ATO can help improve the capacity of the rail network (Belgian Rail, 2016). The CEO of NMBS envisions self-driving trains in 2022 (De Standaard, 2016). In fall 2017, NMBS and Alstom executed trials for ATO over ETCS (level 1). Tests on tracks with varying characteristics are executed: tracks without stops (Bertrix-Virton) and with several stops (Brussels-Leuven). Also, track section speeds and height profiles vary. In these tests, the exact route is known (including track sections) in advance.

Australia - Rio Tinto

Period
2017- 2018

GoA
4

Scope
Rio Tinto iron ore operation: 100 km trial journey

Results
Reduced variability, increased speed, reduced average cycle times

Future deployment
End of 2018

2.2.6 Australia – Rio Tinto

The Australian mining company Rio Tinto had a world premier in 2017: they completed the world's first autonomous rail (freight) journey. The nearly 100-kilometre pilot run was completed without a driver on board (Rio Tinto, 2017). This pilot was an important step towards Rio Tinto's vision of fully driverless operations by the end of 2018. Rio Tinto runs about 200 locomotives on more than 1,700 km of track, hauling ore from 16 mines to four port terminals.

The majority (90%) of Rio Tinto's fleet is AutoHaul-enhanced, which means that trains are able to operate continuously – and more safely – without shift changes. Trains respond automatically to speed limits and alarms (Mining, 2017). AutoHaul is the Australian ATO system.

The project has already seen results like reduced variability, increased speed and reduced average cycle times. These results were achieved by the autonomous system without input from the operators that were active on the train. As a consequence, new roles will be created for the current driver workforce to ensure they remain a part of the organisation.

Germany - Deutsche Bahn

Period
Present-2021

GoA
2/3 and 4 (shunting)

Scope
GoA 2/3: Section of the S-Bahn Line 21 Berliner Tor - Bergedorf/ Aumühle stations (23 km)
GoA 4: shunting area - Bergedorf platform (1 km)

Results
Not yet

Future deployment
Full digitalisation of the Hamburg S-Bahn Network.

2.2.7 Germany

The German Deutsche Bahn (DB) aims to use digital technologies to improve the rail network's capacity in its 'Digital Rail for Germany' program.

In July 2018, DB, Siemens and Hamburg signed a cooperation agreement for the 'Digital S-Bahn Hamburg'. This cooperation aims to have four fully automatically operating trains on a pilot line by the opening of the Intelligent Transport Systems (ITS) World Congress in October 2021 (Press Release Deutsche Bahn, 2018).
On a specified section of the track between the Berliner Tor and Bergedorf/Aumühle Stations (23 km), ATO will be combined with ETCS level 2. The train driver will be on board in each train. The driver will intervene in operations only if required, such as in the case of disturbances in the system or irregularities. This represents GoA 2-3.

For shunting, DB aims to achieve GoA 4 by 2021. Trains will operate without personnel on board for a distance of one kilometre, between the shunting area and Bergedorf station.

Once these pilots are proven to be successful, DB aims to further digitalise the Hamburg S-Bahn Network.
Its aim is to improve the throughput of trains and the mobility offering for passengers.

2.3 TIMELINE OF ATO DEVELOPMENTS IN THE NETHERLANDS

The aforementioned developments show that (the potential of) ATO is being explored, developed and implemented, both internationally and in the Netherlands. We now consider the development stages for ATO: which steps and issues have to be taken into account for the implementation of and the transition towards ATO?

ATO developments in the Netherlands are expected to follow a general timeline (see Figure 4). For the different stages, different functionalities and requirements must be accounted for.

Based on the results of the foreseen trials, it is presumed that ATO will deliver added value. It will further optimise the traffic management function and allow more trains on the tracks. Therefore, a clear business case must be leading in the further adoption of and migration to a national ATO rollout in the Netherlands.

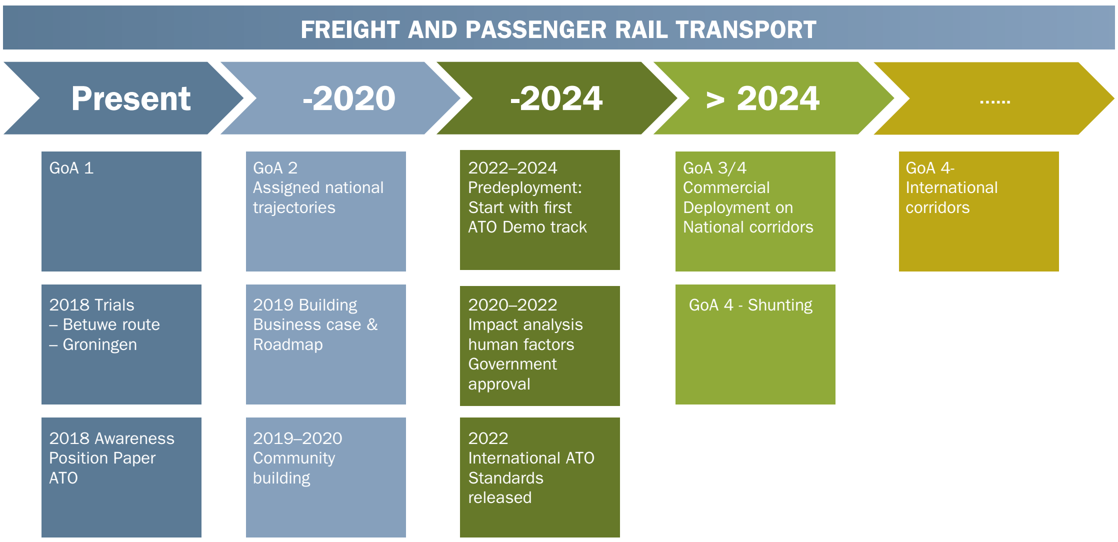
The adoption of and migration to ATO is a step-by-step process. Users' acceptance of ATO is very important. Their working environment will change, as ATO will automate some of their functions. It is important to guide users towards acceptance and give them new tasks that are meaningful for both them and the system as a whole. Furthermore, there will be several technical challenges. For example: how do we connect the existing ATB systems to the new ATO systems? Will be it necessary to alter the existing traffic management systems to work with ATO? The Dutch trials will test these, and many other pertinent questions (see 2.1.).

Based on the information from the trials, it will be possible to define what the next steps must be. Will it be possible to have assigned national trajectories by 2024? What actions are needed? Do we need more tests? What needs to been done to accelerate user and resident acceptance?

In the roadmap and planning, is very important to include enough time to elucidate the impact on the following aspects:

- Safety and security
- Legislation
- User acceptance
- Human behaviour
- Technical and infrastructural development

Figure 4 - Timeline of ATO developments



3. WHO'S WHO IN ATO: STAKEHOLDER ANALYSIS

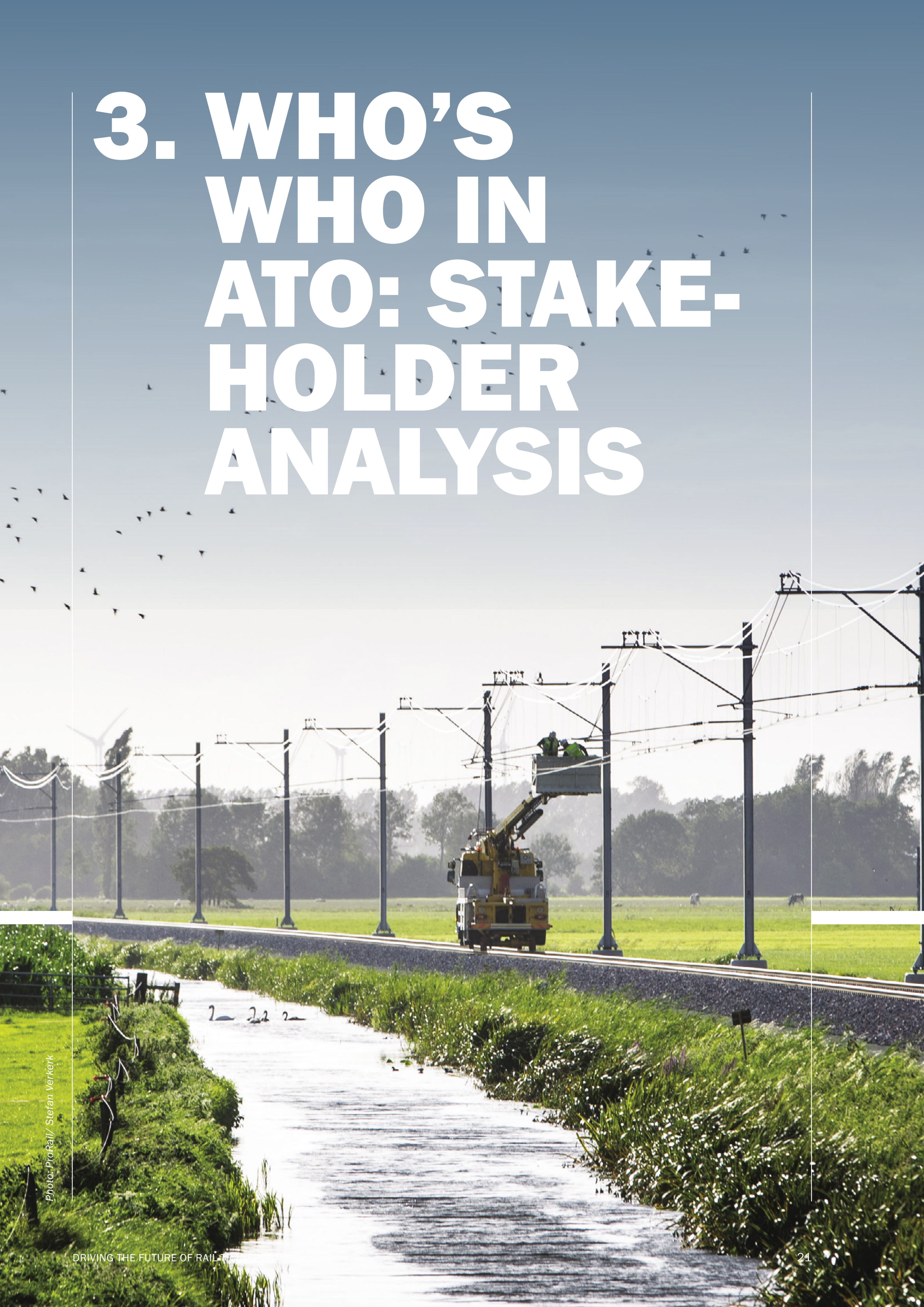


Photo: ProRail/ Stefan Verkerk

ATO will cause a shift in passenger mobility, logistics and the supply chain network. More specifically: ATO involves a system-wide innovation that impacts every party involved with rail passenger transport, shipping and transportation. In order to deploy ATO in society, a concerted effort from all stakeholders is needed.

ATO INVOLVES A SYSTEM-WIDE INNOVATION THAT IMPACTS EVERY PARTY INVOLVED WITH RAIL PASSENGER TRANSPORT, SHIPPING AND TRANSPORTATION.

This chapter describes the parties involved in the introduction of ATO. It also explains their (changing) roles as they attempt to achieve commercial deployment of ATO in the near future.

3.1 THE KEY PLAYERS

To realise ATO, we recognise six key stakeholder categories (see Figure 5). On the commercial side of the innovation, key stakeholders are (1) developers, (2) users and (3) logistics parties. Then, there is the enabling side of the innovation, consisting of (4) regulators and (5) policymakers. Lastly, there is (6) society. Of course, stakeholders can be united or represented in groups, such as branch organisations.
We consider these unions to be part of the stakeholder group. For instance, a branch organisation for LSPs is considered part of the LSP group. We discuss each stakeholder's interest and roles in ATO in the next section.

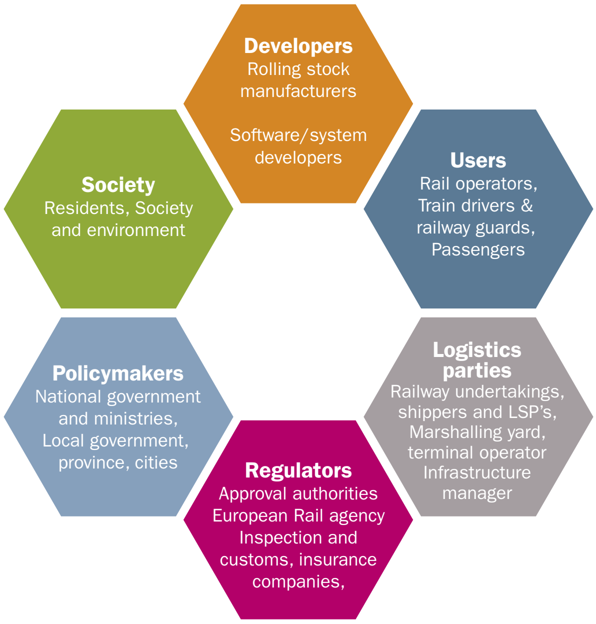
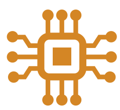


Figure 5 - Stakeholders in ATO

3.2 DEVELOPERS

Developers are involved in the technical development and facilitation of the equipment and complementary technologies. There are two distinct sub-groups here:

Rolling stock/Train manufacturers, Original Equipment Manufacturers (OEMs). Rolling stock manufacturers (such as Alstom, Bombardier, Siemens and Stadler) produce locomotives and trains. They can integrate technological innovations – in their role as OEM – that enable ATO, primarily through the European Train Control System (ETCS) and European Rail Traffic Management System (ERTMS). For the manufacturer, first-mover advantages apply. Being the first manufacturer to deliver locomotives and trains that are able to automatically accelerate and brake on the track will offer the opportunity to gather a bigger market share. Other advantages are insights into the test requirements and type approval, and a positive effect on image and marketing. Although first-movers gain advantage, it is in the interest of all manufacturers to achieve standardisation and compatibility of ATO technology among different makes and brands.
In the long run, manufacturers can among others benefit from the improved competitiveness of the rail sector which is expected if ATO brings about the values as described in Chapter 4. With respect to the development of ATO (see 2.3), the rolling stock manufacturer's role is primarily concerned with technological developments.



Software/system integrators. Software and system integrators provide the software and hardware that is needed to integrate the new ATO systems into the existing systems that Rail Infrastructure Manager (IM) and Railway Undertakings (RUs) use. This will allow IMs and RUs to monitor the traffic on the track in real time and obtain actual times of arrival.

3.3 USERS

Several parties involved in rail use trains to get goods or passengers from A to B and will benefit from ATO in a different way.

Rail operators. Rail operators are the people working in and around the train. Train drivers and train guards are both affected by ATO, but train drivers are affected the most. The nature of train drivers' tasks will change dramatically as GoAs increase. Testimonials from train drivers in the Czech Republic – who are driving trains equipped with ATO GoA 2 – state that their workload has decreased and that it has improved their job satisfaction. Also, ATO can support train drivers and guards in the dangerous and dull tasks at, for example, shunting yards. When ATO can eliminate or support these tasks, rail operators' job quality can be improved.

Passengers. Passengers are not direct users of ATO, but are directly affected by it. Especially as GoAs advance, more of the driver's tasks will be automated. Passengers will have to get used to the idea that a system is taking over more and more tasks. Also, getting on and off the train might become different for passengers as GoAs advance if the ATO system determines when doors close, for example. The main concern for passengers is the perception of safety. In addition, passengers will reap the benefits of ATO, since train punctuality is expected to improve.

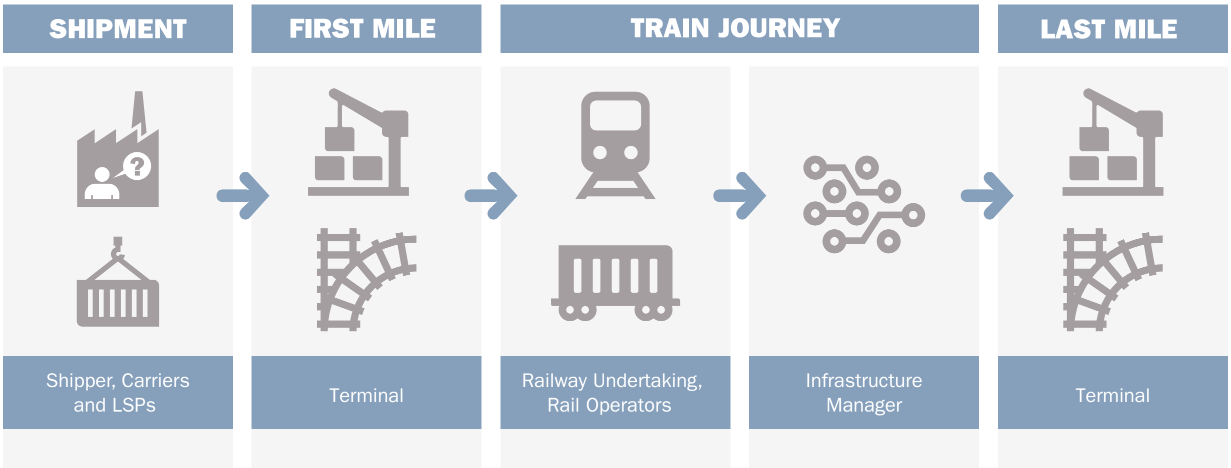


Figure 6 - Logistics parties

3.4 LOGISTICS PARTIES

The logistics parties active in the rail network are displayed in Figure 6.

Railway Undertakings. Railway Undertakings (RUs) are authorised to carry people or goods by rail. RUs are responsible for making sure that passenger transport or the shippers' cargo transport is organised according to the agreed terms.
Among others, ATO will allow passenger transport RUs to increase the frequency of trains (due to capacity optimisation) that may allow for timetable-less travel.

In freight transport, RUs offer container capacity on their rail shuttle services that vary in origin and destination, frequency and price. An RU provides the required traction (both diesel and electric) to physically transport cargo by train to its destination. Having the skills to work with new technologies is an important condition for exploiting its potential. Those Railway Undertakings that are innovative and early adopters of new technologies will be the first to benefit from ATO. Among others, in shunting areas, ATO could not only provide for cleaner energy solutions, but also allow train drivers to be deployed differently and more efficiently, which might improve job satisfaction.

Infrastructure Managers. The implications of ATO for Infrastructure Managers (IMs) are both technical and process-oriented. To be able to increase available capacity and its utilisation in the infrastructure, IMs need to interact with RUs and test the ATO technology together. In this way, requirements and needs will become familiar, and the approach to exploiting its potential will be streamlined. Monitoring trains that drive more closely to one another requires ATO technology, but also the relevant skills of the people involved.

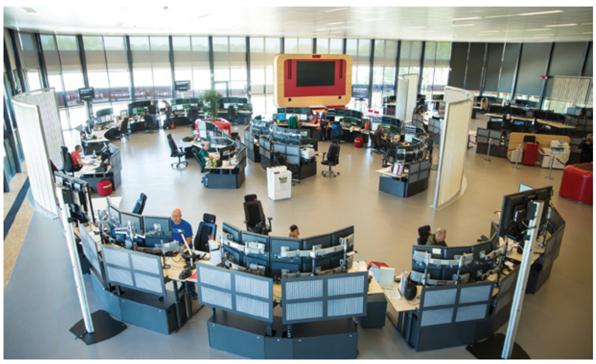


Photo: ProRail/ Stefan Verkerk

The IM's traffic management and control tasks are also affected. As GoAs increase, traffic management will shift from more redirecting tasks towards directing. Only exception management will be executed, as ATO will support and perform the day-to-day operations.

Shippers. Shippers want their cargo to be transported between different locations. More often than not, they agree on terms with Railway Undertakings, who are responsible for doing so. Their influence on deciding which rail operator to choose for handling their cargo will impact the implementation and adaption of ATO in the railway sector. Rail operators that offer the benefits of ATO – such as improved service reliability and flexibility or a lower price – will be preferred over those that do not.

Carriers and LSPs. Carriers and Logistic Service Providers (LSPs) transport products that shippers commission. Due to their central position in the sector, they have the opportunity to play a key role in the transition towards ATO. They will be able to offer more efficient services to their customers.

Terminals. As the value case scenarios in Chapter 4 will show, ATO holds great potential for shunting at marshalling yards. Therefore, marshalling yards and terminals can play a vital role in the transition towards ATO. In particular, terminals can further operationalise the automatisation of their processes and smooth connection with other modalities.

3.5 REGULATORS

Regulators enforce the law or make the law implementable. The most important regulators for ATO are:

Inspection Living Environment and Transport IL&T. The IL&T manages the process of new and adapted existing trains gaining access to the Dutch Railway Infrastructure, with an aim of improving safety. Trains equipped with ATO technology must fulfil the safety requirements of the IL&T. These safety requirements have an impact on various aspects of ATO. For example, the division of tasks between ATO and the train driver.

Customs. The Customs Authority has procedures (and documents required) for cargo. The train driver needs to be able to show the documents when needed. ATO may also require new customs legislation to be developed.

3.6 POLICYMAKERS

Both on the national and local government level, policymakers and/or policy executors are important stakeholders for ATO. In the longer run, the European Union might play a role with respect to policymaking for harmonisation of ATO across European borders.

National government. The Ministry of Infrastructure and Water Management is focused on promoting enabling innovations in the Netherlands. These innovations can target better usage of existing infrastructure, increased accessibility and reduced environmental impact of the transportation system. The Ministry of Economic Affairs and Climate Policy is interested in the competitiveness of the Netherlands: using high-end technological innovations to maintain a strong position in Europe. The ministry has various subsidy programs that could integrate ATO.

Local governments. Local governments, such as provinces and cities, can play an important role in facilitating tests and pilots. The interest of local authorities is to increase the level of innovation in their region. They can facilitate ATO testing on local tracks.

European Union. The EU wants to improve the competitiveness and sustainability of the EU transport system. A modal shift towards rail from road is stimulated in that regard. But innovations are required to realise them. EU policymakers should enable guidelines under which ATO can be tested for improving interoperability between member states. Improved interoperability, in turn, improves the reliability of the rail product.

3.7 SOCIETY

Lastly, society is an important stakeholder group. ATO developments in the rail sector will impact society, and the environment as well.

Residents. ATO will help improve the capacity utilisation of the rail network. This will lead to more rail traffic that will affect residents. Furthermore, safety perceptions are also important to this stakeholder group. For those living near the railway tracks, will their perception change when GoAs increase? This stakeholder group should be involved in the implementation path of ATO.

Environment. It has been shown that ATO helps improve energy efficiency (see section 4.1). Less energy is needed for train operations, and thus ATO has a positive influence on the environment, by reducing CO_2 emissions.

4. THE ADDED VALUE OF ATO

VALUE CASE ANALYSIS

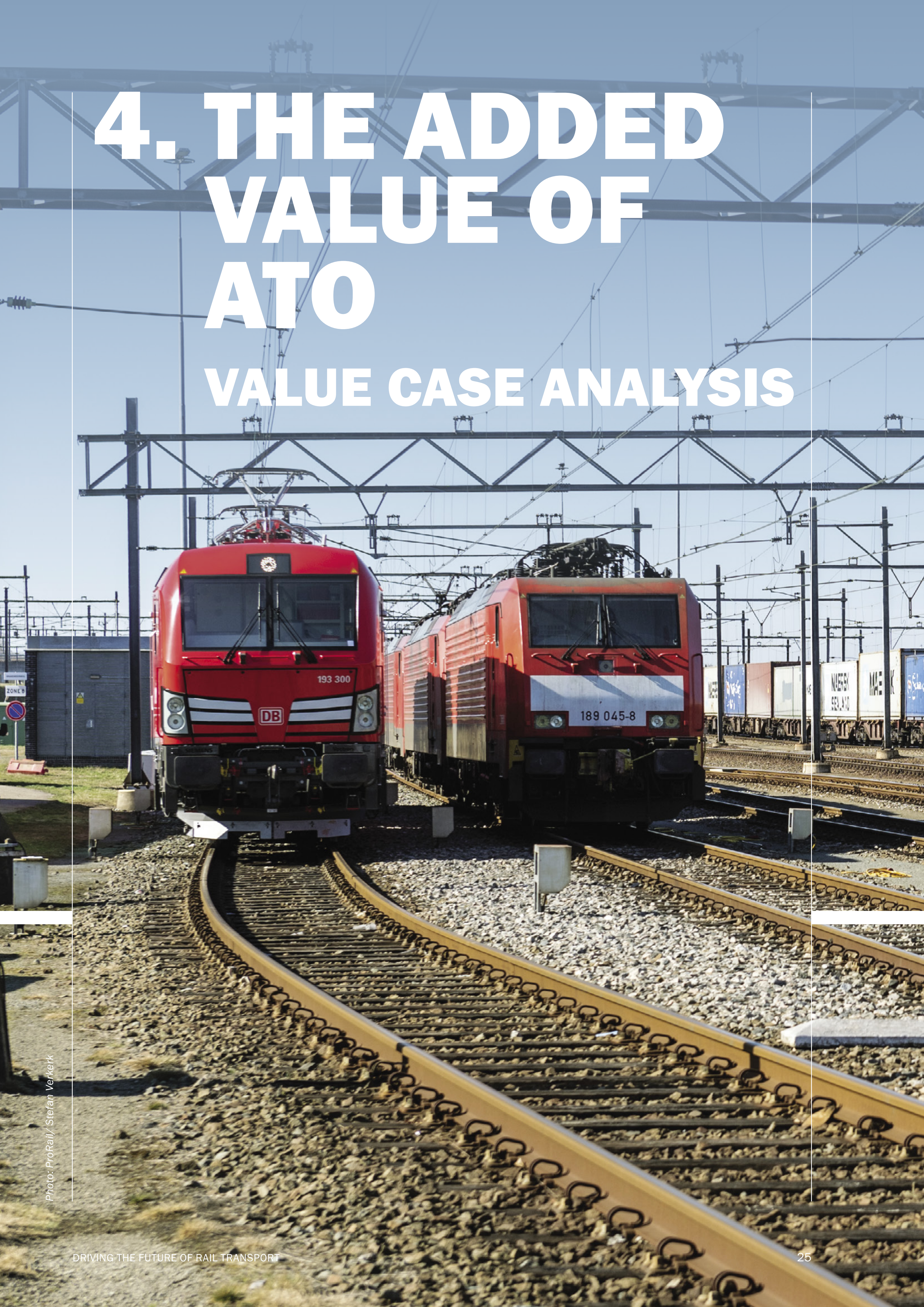


Photo: ProRail/ Stefan Verkerk

In the Netherlands, infrastructure manager ProRail, rolling stock manufacturer Alstom, Railway Undertakings Arriva and Rotterdam Rail Feeding and Province of Groningen are motivated to explore the potential of ATO in testing pilots (see 2.1). If the pilots are successful, the companies aim for further development. When societal benefits are abundant, the government is encouraged to adjust regulation if needed and enable deployment of this innovation in the rail sector.

First, the business and societal benefits are described. Subsequently, these are explored in more detail in three different value case scenarios.

4.1 BUSINESS VALUE AND SOCIETAL VALUE

ATO has the potential to deliver many business and societal benefits, leading to improved competitiveness of the sector in comparison to other transport modes. Figure 7 shows the key benefits that we explain in more detail.

ATO HAS THE POTENTIAL TO DELIVER MANY BUSINESS AND SOCIETAL BENEFITS.

Optimisation of capacity utilisation

Capacity of the rail infrastructure can be better utilised. From GoA 2 onwards, ATO takes over braking and acceleration. As a result, there is less variability in driving behaviour. Furthermore, it is possible to approach the permitted braking curve at the closest curve possible. As a result, ATO-driven trains can follow one another more closely for shorter headways, which allows for more trains on the same amount of rail infrastructure. For example, in the United Kingdom, ATO applications (Thameslink) propose to drive 24 trains per hour (70% more seats) through the city centre of London. Improved capacity utilisation is especially valuable for IMs, RUs, carriers and LSPs. This is also valuable for passengers, as more frequent trains are possible (timetable-less travel). For the Netherlands and the sector at large, this will lead to an improved competitive position of rail transport (both passenger and freight). Rail can be a very attractive mode of transport if capacity utilisation is improved considerably.

When capacity utilisation is optimised, the current infrastructure does not require such elaborate extension. As a consequence, large infrastructure investments can be delayed or will not be necessary at all.

Minimisation of energy consumption and reduced wear & tear

Thameslink shows that energy consumption can be minimised, although exact numbers are not (yet) known. ATO calculates and controls the optimal speed profile to get the train to the next station using the minimum energy in the time given by ATS. When time permits, ATO will coast before braking to save energy (see Figure 8). Alstom's simulation tests show that on intercity lines, energy can

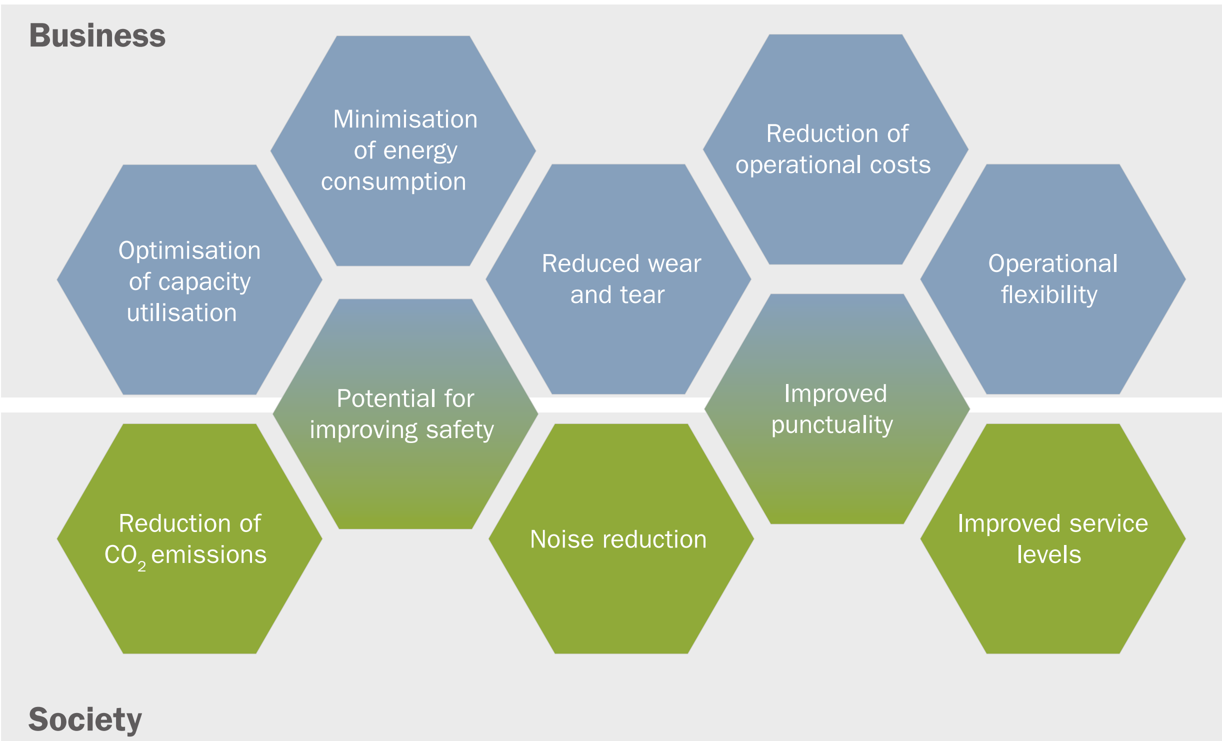


Figure 7 - Business and societal value of ATO

typically be reduced by 15%, and on regional trains by 45%. Experiences in the Czech Republic show 15-30% energy savings, depending on timetables, delays and locomotives used.

Because of optimal braking curves, material wear and tear can be reduced. ATO systems provide data on braking and accelerating locations on the track.
As a result maintenance will be more predictable and efficient. These benefits are especially valuable for RUs and IMs, as these reduce the exploitation costs.
For society, the minimisation of energy consumption results in a reduction of CO_2 emissions and less pollution. Also, the optimal braking curve leads to noise reduction and improved comfort for passengers, train drivers and residents living near railway tracks.

Reduction of operational costs
ATO has the potential to reduce costs in several ways for several stakeholders. For RUs, costs can be reduced through the reduction of energy consumption. Also, reduced wear and tear leads to improved maintenance intervals and optimal use of assets. For IMs, the distributed load of trains results in a reduced wear and tear of the infrastructure. Again, maintenance intervals are improved and the existing infrastructure is used more efficiently. Other logistics parties also benefit, as disturbances caused by maintenance occur in fewer intervals.

Operational flexibility
ATO improves operational flexibility in case of distortions or extra demand in transport. For example, ATO contributes to flexibility when distortions occur, as no re-planning of staff is required. Currently, route knowledge is required. As ATO supports the train driver, this is no longer the case and thus personnel planning can be more easily adjusted to unexpected events.

Furthermore, ATO can be used for improving situational awareness on trains. When two trains approach a railway junction, ATO can support the blending in of trains by adjusting the speed based on the speed profile of the approaching train. As such, the system becomes more flexible, while at the same time managing safety.

Potential safety improvement
ATO has potential to improve safety. To date, it has been proven that implemented ATO complies with existing safety standards. However, it is not yet certain whether it can also improve safety. The potential is clear, though, since the train driver is supported considerably with his/her tasks. By reducing the workload for the train driver, ATO eliminates human error in routine tasks and minimises human error in non-routine tasks. It should
be noted that the train-driver-ATO interaction should be carefully considered, since the train driver (at lower GoAs) still should be able to be focused enough to interfere with the system. If ATO is combined with a combination of sensors – like a thermal camera, 3D laser scanner, night vision camera and stereo cameras – it will be possible to spot all kind of objects on the track up to a 1000 metres in front of the train. This will further improve the safety levels and lower the driver's stress level (Shift2Rail, sd; SMART, 2016). An increase in safety will create a higher feeling of security in residents living near the track.

Improved punctuality
ATO can ensure better punctuality by reducing headway between trains and utilising additional options to reduce delays. In addition, shorter halting times are required because they are less dependent on the human factor.

Thus, better on-time arrival and departure at train stations improves the punctuality of ATO-equipped passenger and freight trains. This is beneficial for both passengers and logistics parties. The latter are dependent on punctual arrival of trains at terminals, for example.

Improved service levels
The different enhancements offered by ATO improve service levels across the board. The improved punctuality and shorter dwell times offer higher levels of service for both passengers and logistics parties.

Also, in the case of passenger transport, the optimised braking curve contributes to improved passenger comfort. At GoA 3 or GoA 4, train drivers can also execute more service-oriented tasks that contribute to passenger satisfaction.

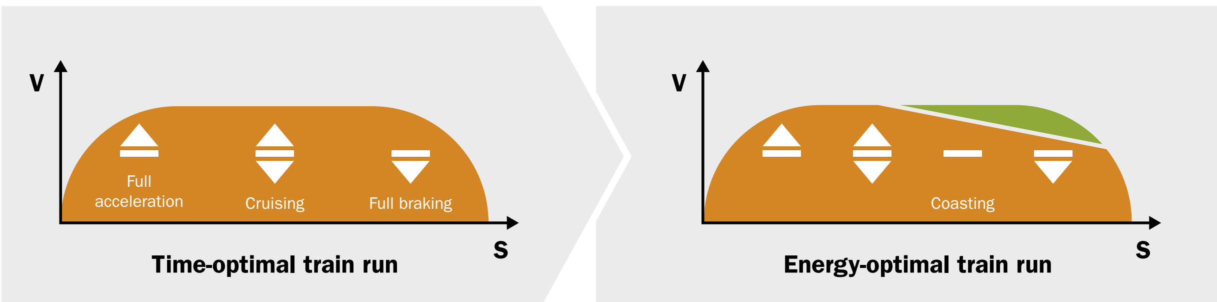


Figure 8 - Minimisation of energy and wear (Siemens, 2014)

4.2 VALUE CASE SCENARIOS

We would now like to explore three different value case scenarios. These are linked to the timeline of ATO developments as envisioned in Chapter 2 (Figure 4: Timeline of ATO developments). Of course, these value case scenarios are not reality yet, but they have the potential to be realised, as we demonstrate here. The aim is to provide a glimpse into the future and the possibilities that are at hand. Value case Scenario A shows the possibilities in the short term – GoA 2 for a demarcated railway track. Scenario B shows potential in the middle-long term – GoA 4 for shunting. And lastly, Scenario C shows us the longer-term perspective, in which GoA 4 is realised on international corridors.

ATO VALUE CASE SCENARIOS: FROM SHORT-TERM POSSIBILITIES TO LONGER-TERM VISION

4.2.1 Freight transport versus passenger transport

As exemplified in the three value case scenarios, the differences between ATO for freight transport and ATO for passenger transport are not very significant. Both have the potential for significant benefits (e.g. energy savings, CO_2 reductions, punctuality). Here, we want to highlight a few of the differences between the two modes of rail transport (see Table 3).

For freight transport, minimising energy consumption is an important objective. The value that results from energy savings is greater for freight transport than for passenger transport. One can imagine that efficiently braking a cargo train (with a maximum weight of 4,680 tons) can result in enormous energy savings. In addition, reducing slack in the logistics chain is a very important benefit that results from the improved punctuality and efficient use of time slots at yards or transhipment points, such as terminals. Just-in-time arrival and departure becomes possible. The value from improved information sharing will be the largest for freight transport if all logistics chain parties are synchronised. Improved punctuality is also related to better throughput of trains. Currently, cargo trains often have to wait for passenger trains to pass. ATO will allow for better throughput because of situational awareness functionalities in the higher GoAs. Lastly, capacity improvement is important for rail freight transport. With respect to shunting (at GoA 4), we expect that for freight transport, the primary benefit lies in eliminating dull and dangerous tasks for train personnel, thereby improving employee satisfaction.

For passenger transport, improved capacity is expected to be of high value, as the number of travellers is expected to increase even more in the next couple of years. Also, punctuality and the possibility of timetable-less travel are important value drivers for the passenger segment. With respect to shunting (GoA 4), we expect to be able to reduce unnecessary travel time for personnel to/from yards. Also, rolling stock can be sent to regular tracks that can be used as yard overnight.

4.2.2 General value versus additional value

Some benefits apply to all value case scenarios, such as improved punctuality and energy savings. We label these as 'general values'. In the value case scenarios below, these are displayed with small text and icons. 'Additional values' are benefits that add up to these general values, and these are displayed with large text and icons (see value case Scenario B and C).

	Freight transport 	Passenger transport 
General (Value Case A + C)	Minimisation of energy consumption; Improved punctuality: better throughput, efficient use of yard slots	Optimisation of capacity utilisation; Improved punctuality: timetable-less travel
Shunting GoA 4 (Value Case B)	Improved employee satisfaction: dull and dangerous tasks can be eliminated	Improved employee satisfaction: reduce unnecessary travelling to/from yards; Rolling stock can be sent automatically to train wash/regular tracks as yard overnight

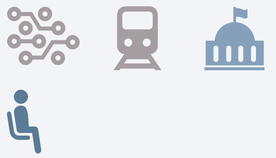
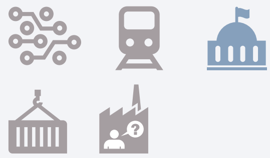
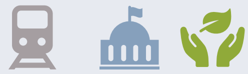
Table 3 – Main values freight transport and passenger transport

Legend

Infra-structure Manager | Railway Undertaking | Carriers and LSPs | Terminals | Shippers | Rail operators | Passengers | National government | European Union | Residents | Environ-ment

VALUE CASE SCENARIO A – GOA 2 FOR DEMARCATED RAILWAY TRACK

In this value case scenario, GoA 2 for a demarcated railway track is explored in more detail. Imagine a 100-kilometre part of the track of the Betuweroute (freight transport) or the Schiphol tunnel (passenger transport). **Trains will drive semi-automatically over a specified distance.** This implies that – for both freight and passenger locomotives – train operations such as setting the train in motion and braking are automated.

	Value	Beneficiaries	
		Passenger transport	Freight transport
General values	Optimisation of capacity utilisation		
	Minimisation of energy consumption		
	Reduced wear and tear		
	Improved punctuality		
	Train driver can focus on other activities (improve service levels)		
	Potential for improved safety		
	Less pollution due to efficient braking and reduction of energy use		

VALUE CASE SCENARIO B – GOA 4 SHUNTING

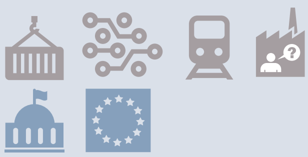
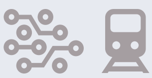
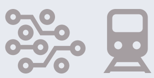
In this value case scenario, GoA 4 for shunting is explored in more detail. **Trains will drive fully automatically between terminals and the marshalling yard.**

This implies that – for both freight and passenger locomotives – all train operations (setting train in motion, braking, operation in event of disruption) are fully automated and the train operation is not attended by a driver. Other operational tasks might be assigned to the driver.

	Value	Beneficiaries: Passenger transport	Beneficiaries: Freight transport
Additional value	Cost reduction – drivers are not needed for unattended train operation		
	Improved flexibility- possible to use regular tracks that are less accessible for train personnel as yard overnight		
	Improved employee satisfaction, dull and dangerous tasks can be eliminated, unnecessary travel time can be avoided		
General value	Improved punctuality and efficient use of yard slots		
	Minimisation of energy consumption		
	Reduced wear and tear		
	Less pollution due to efficient braking and reduction of energy use		

VALUE CASE SCENARIO C – GOA 4 LONG-DISTANCE INTERNATIONAL CORRIDORS

In this value case scenario, GoA 4 for long-distance international corridors is explored in more detail. Trains will drive fully automatically on long-distance international corridors. This implies that – for both freight and passenger locomotives – all train operations (setting train in motion, braking, operation in event of disruption) are fully automated and thus no driver is needed on the train.

	Value	Beneficiaries: Passenger transport	Beneficiaries: Freight transport
Additional value	Improved flexibility: No change of driver required at borders due to language or system knowledge requirements		
	Improved flexibility: If alternative routes should be taken in case of disruptions, no driver with route knowledge is required		
	Improved punctuality		
General value	Optimisation of capacity utilisation		
	Improved punctuality and efficient use of yard slots		
	Minimisation of energy consumption		
	Reduced wear and tear		
	Less pollution due to efficient braking and reduction of energy use		
	Potential for improved safety		

5. CONDITIONS TO SUCCEED

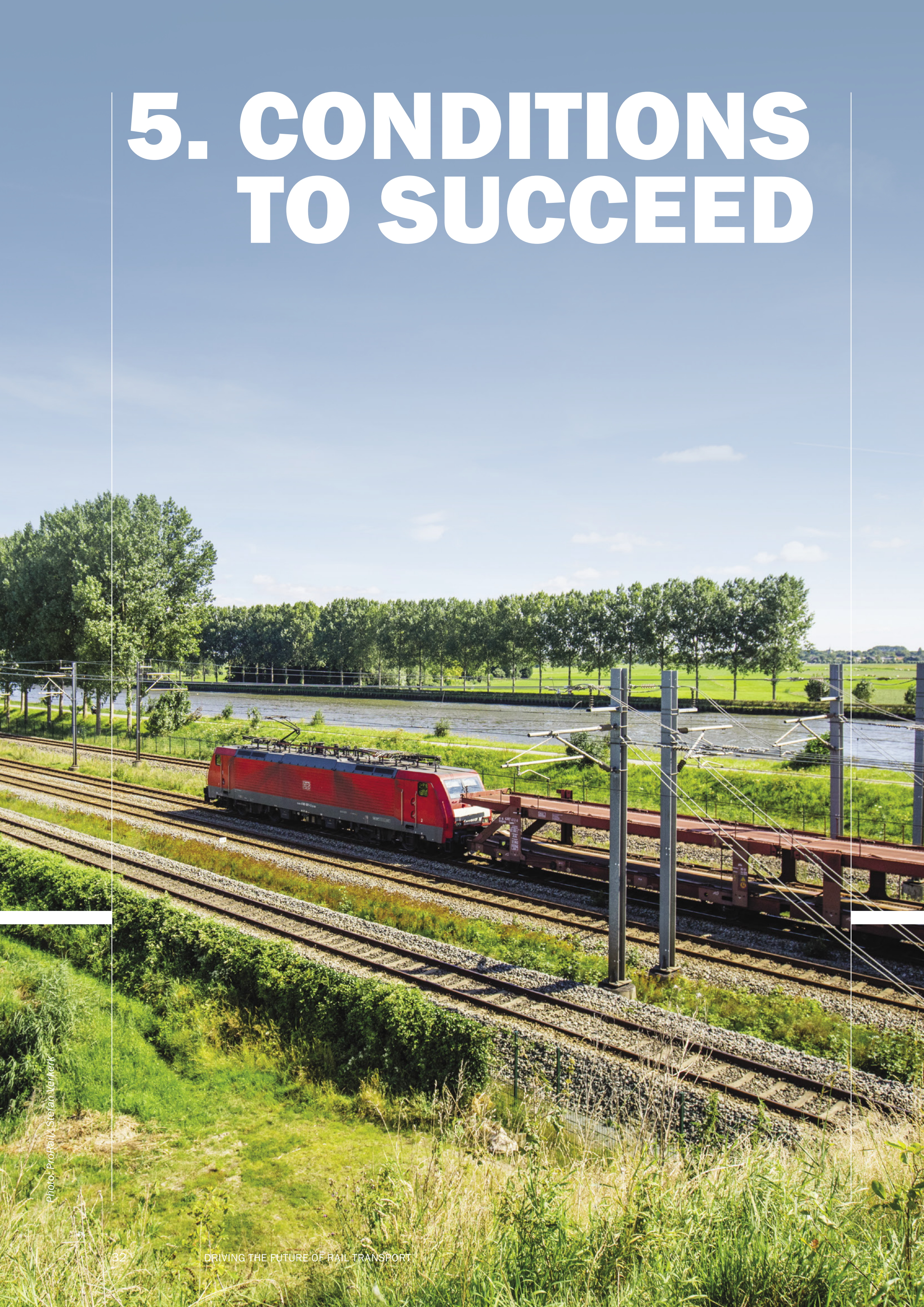
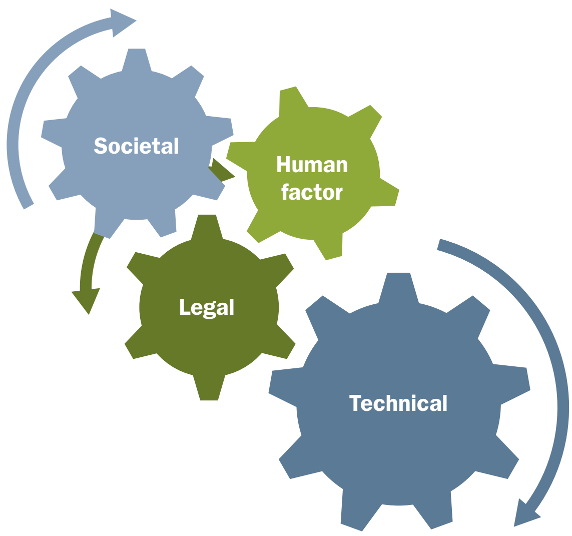


Photo: ProRail / Stefan Verkerk

ATO is not yet a reality in the Netherlands. We have identified several conditions required to bring ATO to implementation. These are classified into various domains: technical, legal, human and societal (see Figure 9). As can be seen, these domains are all intertwined. The technical specifications of ATO influence the liability issues in the legal domain. These in turn, affect the human factor: train drivers' willingness to work with ATO and the rail sector as a whole's willingness to change. Public opinion is affected by how the rail sector presents itself in relation to ATO, and how the first tests trials are executed.

Figure 9 - Conditions to succeed



5.1 CONDITIONS FOR SUCCESS IN VARIOUS DOMAINS

Technical domain

As ATO has been successfully implemented on various international trains (see Chapter 2), the locomotive suppliers for the Dutch pilots indicate that technical advancements are mature enough to be implemented in the Netherlands, as well. Of course, the pilots have to show that it works in the busy and dense Dutch infrastructure.

For GoA 4, both short- and long-range sensors are necessary for a safe system. In particular, long-range sensors are not yet available. Looking for cross-overs with other technologies or sectors is an important opportunity here.

Furthermore, system safety needs to be ensured at all times. Increasingly, cyber security will be relevant for the rail sector if more and more functions are being automated.

Legal domain

By transferring human tasks to a system, the issue of liability is inevitably raised. To what extent is the train driver liable, and to what extent ATO in case of disruptions? These are hard questions to answer. And these need attention before ATO is fully implemented. Stakeholders in the rail sector need to work together to find a balance. What are the responsibilities of the train driver and Railway Undertaking, and are there any responsibilities that can be assigned to the system?

Human factor

Within the rail sector, a cultural change is expected to happen. ATO requires a new way of working, not only for the train drivers themselves, but also for – amongst others – traffic managers and Infrastructure Managers (a.o. maintenance intervals will change).

The human factor of ATO should not be neglected. A transfer of control to systems needs to take place. When moving from GoA 2 to eventually GoA 4, this transfer of control will be more far-reaching once more driver tasks are transferred to ATO and the nature of the train driver's job changes.

Also, with increasing GoAs, an increased visibility and transparency is created in the rail sector. As such, a mental shift needs to happen to cope with these changes and reap the benefits of these developments. Ultimately, ATO paves the way for a change in organisation in the rail sector: with more collaboration and transparency, slack in the sector can be reduced and competitiveness in the rail sector will be improved.

Societal domain

The general public also plays a vital role in the implementation of ATO. Both passengers and residents living near railway tracks need to support this railway innovation. The perception of safety is very important. People who are travelling by train should feel comfortable enough that the train driver is supported by a system. This will require a mental shift that is typically required with sector-wide innovations.
We should not think lightly about public acceptance. However, we should also keep in mind that in general, people travelling by plane also accept that their plane is controlled by an autopilot the majority of the time.

5.2 START TRIALS TO ACCELERATE INNOVATION!

While it is clear that the opportunities that ATO provides should be explored as soon as possible, we must be ever-mindful of the technical, legal, human and societal challenges that accompany it. Only when all stakeholders work together in the spirit of advancement and optimisation, can the true benefit of ATO be brought to light, and potential obstacles be eliminated. For all, the focus for the future must be safe, reliable, punctual and sustainable rail travel that expands capacity and improves efficiency. At the same time, the solution must be acceptable to the users who will operate the system and the people who will ride upon it.

By starting with the trials in the Netherlands, the expected benefits and the necessary conditions can be further addressed and investigated. This will enable ATO to be implemented in the best possible way. If the trials are successful, the relative innovation speed of rail will be boosted. The rail sector will be prepared for the future: the capacity challenge can be overcome and the competitive position of rail transport can be improved.

Photo: ProRail/ Stefan Verkerk

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NOTES

NOTES

ProRail/Ruud Ploeg

GLOSSARY

ATO	Automatic Train Operation
ATP	Automatic Train Protection
CBTC	Communications-Based Train Control
DAS D	river Advisory Systems
ERA	European Railway Agency
ETCS	European Train Control System
GoA	Grade of Automation
IM	Infrastructure Manager
LSP	Logistics Service Provider
RU	Railway Undertaking
RO	Rail Operator

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