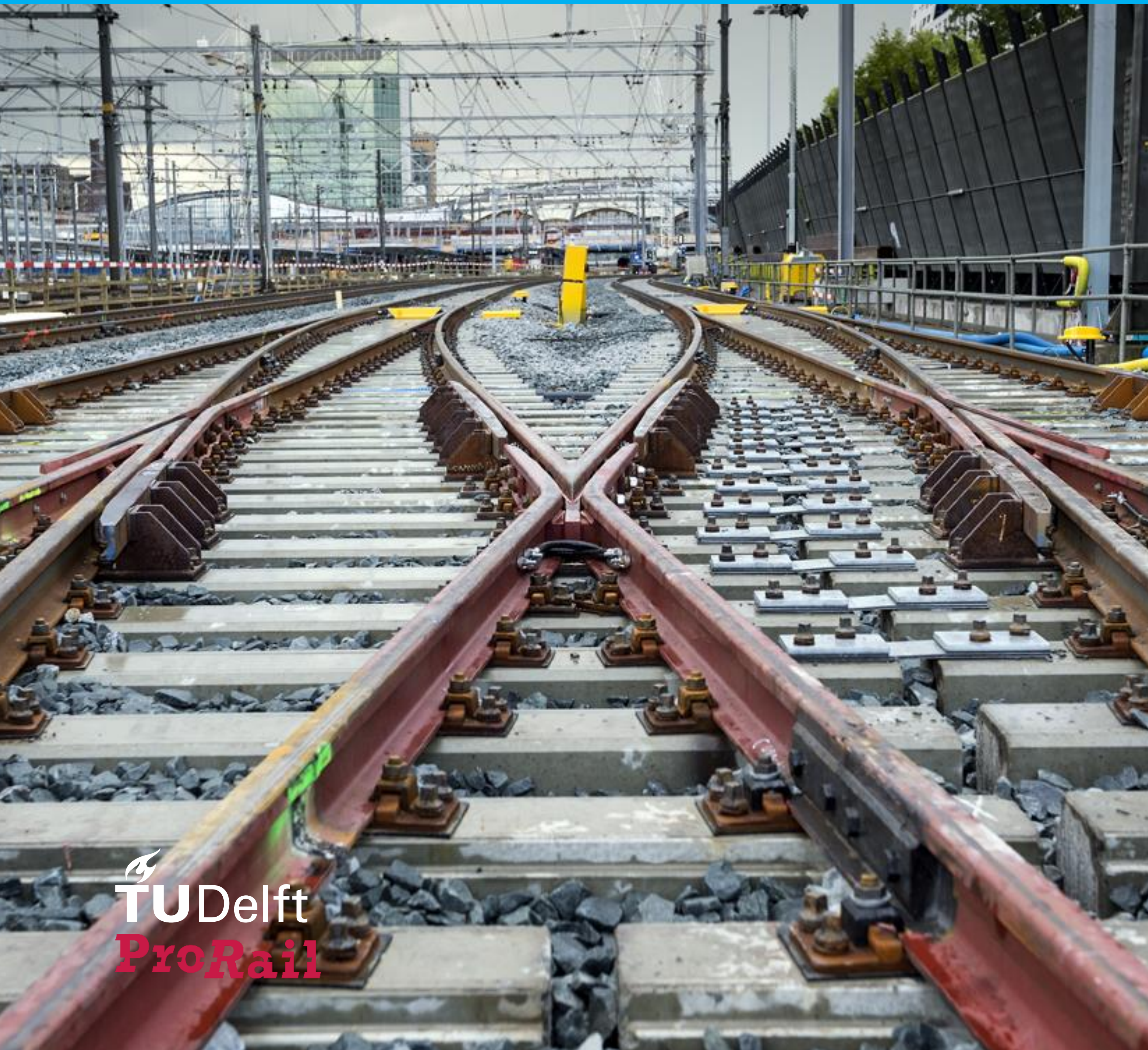
C.P.G. Buurmans

Automatic Train Operation over Legacy Automatic Train Protection Systems

A Case Study on the Groningen-Buitenpost Line



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Automatic Train Operation over Legacy Automatic Train Protection Systems

A Case Study on the Groningen-Buitenpost Line

By

C.P.G. Buurmans

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Thesis committee

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Final report

Disclaimer

ProRail staat achter de inhoud van het afstudeerrapport, maar behoudt zich uiteraard het recht voor om zelf beleid te formuleren ten aanzien van het realiseren van ATO op de huidige ATBNG-baanvakken.

Preface

This report marks the end of my time at the TU-Delft. During the last nine months I have been thinking and writing about automatic train operation over ATBNG. I have learned a lot about automatic train operation and the ATBNG automatic train protection system. It was a challenging process but I think the final report yields some useful insights in ATO over ATBNG.

I preformed this master thesis at the innovation department of ProRail. I want to thank my company supervisor Alfons Schaafsma for providing me this opportunity and for his support and comments during the research.

My supervisors of the TU-Delft have provided a lot of help and feedback during the project. I want to thank Egidio Quaglietta, my daily supervisor, for our talks and his detailed feedback on my work. Furthermore, I want to thank Rob Goverde, the chair of my graduation committee for his feedback. I also want to thank Eleonora Papadimitriou, my second supervisor, for her feedback on my work and acquainting me with the the non-technical aspects of automation.

I also want to thank the other colleagues of the ATO team and ProRail in general. For their insights in ATO, ATBNG, and the ProRail traffic management system. The table football games provided a welcome break from the work.

But foremost I want to thank my parents, Jan and Lia, and my sisters, Tessa and Nadja, who have kept me going for countless times during this project. Without their support I would have never succeeded in finishing this project.

Kristijn Buurmans
Etten-Leur, October 18th 2019

Content

Summary

Railways are facing a challenge to simultaneously increase the capacity and the operational performance of their network. Automatic Train Operation (ATO) is one of the possible technologies which can increase track capacity without adding additional track. ProRail is one of the parties testing Automatic Train Operation. The tests take place on different Automatic Train Protection (ATP) systems including both state of the art European Train Control System (ETCS) equipped railway lines and conventional railways equipped with NS'54 lineside signals and the Dutch national ATP system Automatische TreinBeïnvloeding Nieuwe Generatie (ATBNG). One of these conventional railway lines is Groningen-Buitenpost.

The Aim of the test with ATO is to get insight in the advantages of ATO. The advantages are expected to be, among others, an increase of capacity, reduction of energy use, and an increase of punctuality. Another Goal of the test is to gain insight in the steps which are needed to implement ATO Grade of Automation (GoA) 2[1]. To achieve this goal it is necessary to test ATO on the current automatic train protection system, such as ATBNG. The literature review showed that the requirement specifications for ATO over ETCS have been defined. However, this is not the case for ATO over ATBNG.

The objective of this research is to identify the data gap between ATBNG and ETCS, to support the tests of ATO over ATBNG. The data gap must be closed by identifying sources within other systems. The total set of information exchanged between all the systems (train side systems, ATBNG, and Traffic Management Systems) must provide a complete picture of the train, the rail infrastructure, the route, and the timetable.

The main research question is:

Which concrete steps can be taken towards connecting a future Automatic Train Operation with the Traffic Management System, for Arriva trains on Groningen – Buitenpost?

To support the research to answer the main research question the following sub questions are defined:

- *What functions are expected from the GoA 2 system/ Traffic Management System?*
- *What information is required for a GoA 2 system, both from track to train and vice versa?*
- *Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?*
    - *What information can ATBNG deliver?*
    - *What information should the ProRail TMS system deliver?*
- *Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?*

[1] Under Grade of Automation 2 (GoA 2) the train runs automatically from station to station. The train driver is responsible for supervising the train movements, closing the doors, and to operate the train during disruptions (UITP, 2012).

The research question is answered by developing a conceptual ATO over ATBNG model. This model is developed in four steps:

1. Development of a generic ATO model
2. Conceptual model ATO over ETCS
3. Conceptual model ATO over ATBNG
4. Validation of the conceptual ATO over ATBNG model by three case studies

Generic ATO model

The developed generic ATO model is describes the required input and output data of an ATO system. This model is develop independent of the type of Automatic Train Protection (ATP) system.

The ATO system performs three functions: trajectory generations, trajectory tracking, and tracking/brake command generation. The generic ATO model shows the functions performed by ATO requires five groups of information: safety envelope, timetable, route characteristics, train characteristics, and current status. Three sets of information are outputted by the ATO system: current status, timing point prediction, and control commands.

Conceptual model ATO over ETCS

The generic model is used as a framework to analyse ATO over ETCS. Figure 1 presents the resulting ATO over ETCS conceptual SysML model. The components of the system and the information exchange between the systems is presented. ATO adds two components to the railway control system, seen in the centre of figure 1, the ATO trackside and the ATO onboard.

The ATO trackside receives journey profiles (timetable) and segment profiles (infrastructure description) from ProRail traffic management systems and sends these to the corresponding ATO onboard. The ProRail traffic management system (TMS) must be modified to deliver this information, this is indicated by the new ATO function shown in red. The ATO trackside receives current status and the timing point prediction from the ATO onboard. The timing point prediction is a prediction of arrival times at upcoming locations along the track such as stations. The current status contains the location and speed of the ATO train. The ATO trackside sends this information to the ProRail TMS. Signal operators indicate that this information can improve situational awareness. To present the information a new TMS function is needed. In figure 1, this new function is indicate in red as the ATO Function.

The ATO onboard determines and sends traction/braking commands based on the journey and segment profiles, the ETCS operational envelope, and the train characteristics. The journey and segment profiles are received from the ATO trackside. The ETCS onboard system delivers the parameters of the ETCS operational envelope. The train itself by means of the Train Control Management System (TCMS) delivers train characteristics to the ATO onboard. Furthermore, position information is delivered to the ATO onboard by the ETCS system.

The ATO onboard delivers information to the ATO trackside, the ETCS onboard system, and the traction/braking system. The main function of the information delivered to the ETCS onboard is to provide the train driver with information about the action ATO is taking, including Motoring (accelerating/ cruising), coasting, and braking.

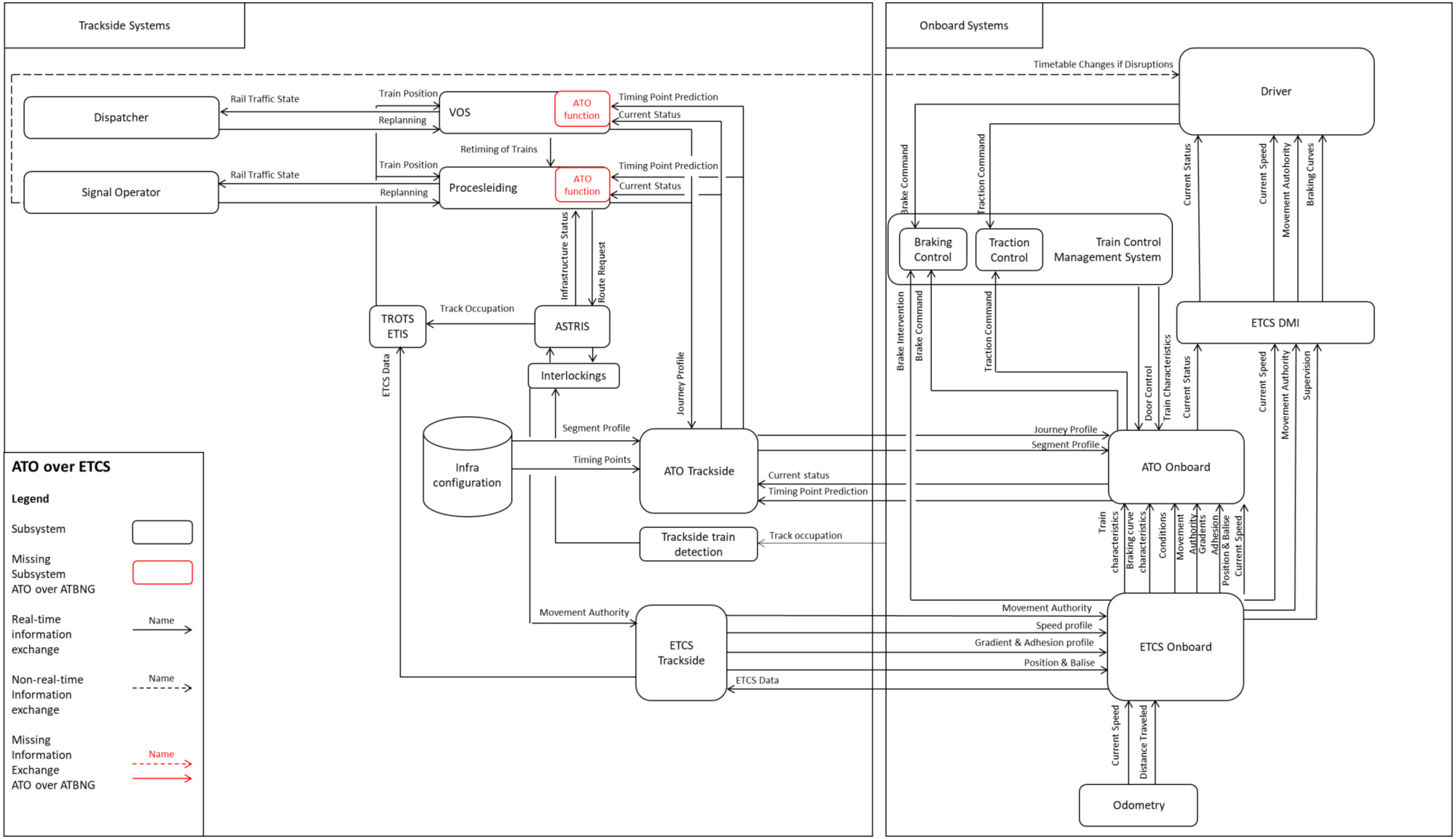


Figure 1 Conceptual model ATO over ETCS.

Conceptual model ATO over ATBNG

The conceptual SysML model of ATO over ETCS is the starting point for the conceptual model of ATO over ATBNG (figure 2). ATBNG takes the place of ETCS in the conceptual model. The ATO onboard must be capable of interpreting the information received from the ATBNG onboard.

The SysML model is used to define which components change moving from ATO over ETCS to ATO over ATBNG. For these components it is determined if the function defined for ATO over ETCS can be executed by the ATO over ATBNG component. Furthermore, it is determined if the component can provide the required information. If the information cannot be provided alternative components are identified.

The first function performed by the ATO onboard is to generate a trajectory. This trajectory is based on the relevant operational envelopes and the goal set within the journey profile. An issue has been identified with determining the relevant operational envelope of ATBNG/NS'54. Delayed braking, meaning braking according the ATBNG operational envelope, is currently not allowed. A choice must be made if delayed braking can be allowed for ATO over ATBNG. The conceptual model presented in this thesis does not take into account delayed braking. Thus the ATO system has to brake according to the orders given by the conventional sequence of signal aspects defined by the Dutch national signalling system NS'54. ATBNG is by itself not capable of fully delivering the NS'54 operational envelope. Additional information must be delivered to the ATO onboard system. Within this thesis multiple options are presented, the most promising take additional information from the traffic management system.

The driver machine interface (DMI) informs the driver of the actions taken by the ATO onboard. ATBNG is equipped with an dedicated DMI. Modifications to the ATBNG DMI is unwanted because it is part of the safety system. Therefore, an additional ATO DMI is required.

Some train characteristics can be delivered by ATBNG, including train length and the number of isolated brakes. Additional train characteristics such as the traction/braking model can be delivered by the train control management system or preloaded into the ATO onboard. If the information is preloaded into the ATO onboard, the ATBNG information can be used to determine the applicable models.

Validation of conceptual model

The SysML ATO over ATBNG conceptual model is validated using three case studies. These case studies include communication with the traffic management, approach to a red signal, and the approach to a level crossing.

The first case study describes an express train entering a single track section being hindered by a delayed local train causing a conflict. The SysML model is used to analyse the steps to be taken to intervene and retime the train. This analysis is made for the current situation, the ATO over ETCS system, and the ATO over ATBNG system. Listing the steps allows the identification of new information available with ATO, such as a prediction of the arrival time at timing points. The analysis resulted in the following findings. The current signalling system and ATBNG not allow for anticipating train control which requires a retiming intervention, which has limited support by the current tools. The case shows that with ATO additional information can be made available to signal operators, including predicted arrival times and automatic updates of the timetable. Furthermore, interviews with signal operators indicate that these information can indeed help the signal operator with retiming interventions.

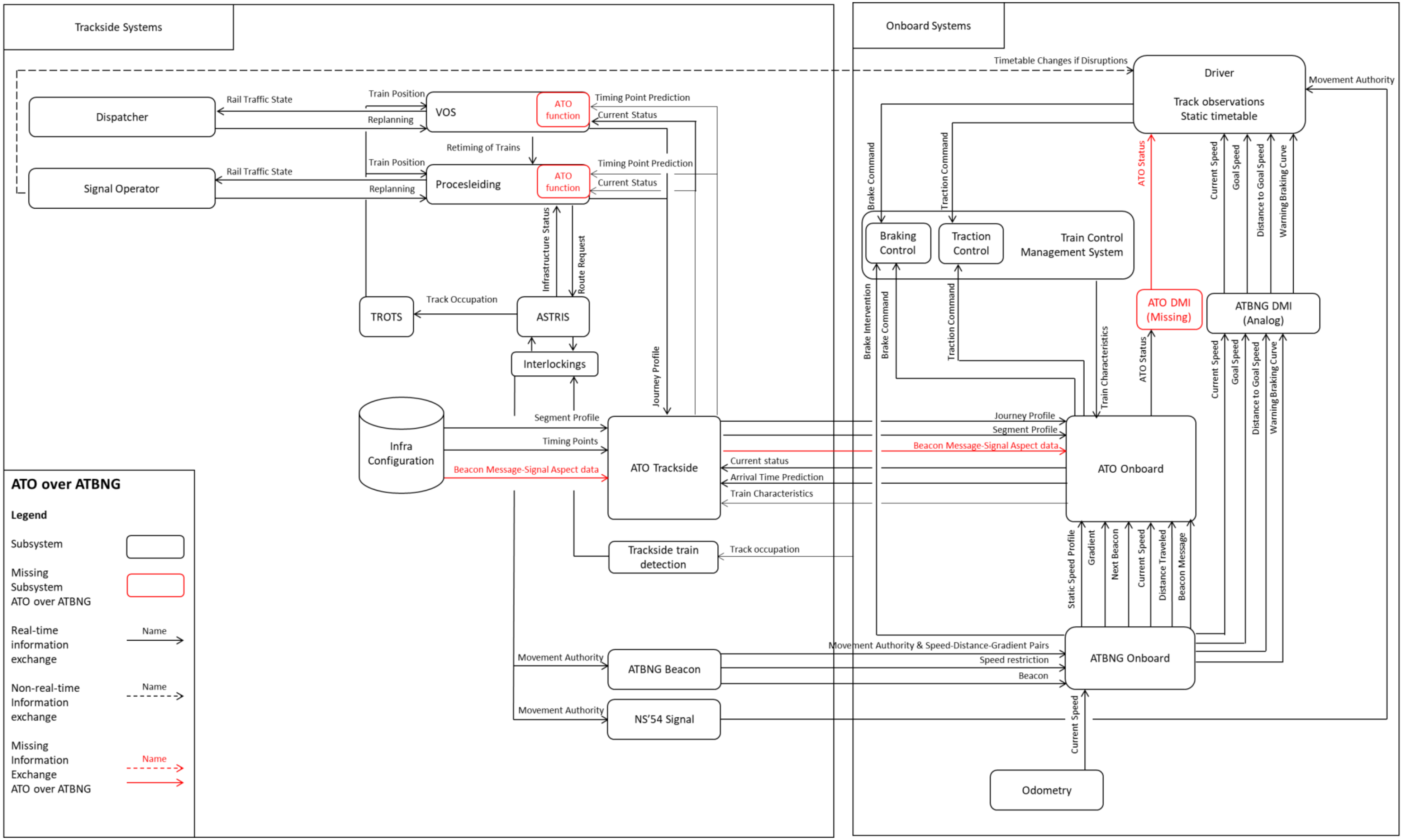


Figure 2 conceptual model ATO over ATBNG.

The second case is a red signal approach case. The conceptual SysML model is used to determine the steps required for an ATO train to determine the signal is red and apply the brakes. Each step is timed, the underlying assumptions are presented in section 7.3.1. Based on the required time it is determined at what distance from the red signal the signal state must be known. From these preliminary calculations it can be concluded that the red signal position is known sufficiently early from a safety perspective. However, from the perspective of performance an issue might arise. Information about the location of the red signal must be known before the yellow signal location above certain speeds. Depending on the speed of the train and the beacon locations performance might be adversely affected and require a longer minimal headway between trains.

The third case, a level crossing case. The SysML model shows that the ATO onboard receives no information which would allow it to determine if the level crossing is clear. The train driver is responsible for determining if the level crossing is clear. However, without ATO this task is part of an active driving task. With ATO the task becomes part of a supervision context. This can result in the out of the loop problem whereby the situation awareness of the train driver reduces and results in longer response times.

Conclusion

The following can be concluded with respect to the research questions.

What functions are expected from the GoA 2 system/Traffic Management System?

The generic ATO model defines three functions for the ATO system: trajectory generation, trajectory tracking, and determination of the traction/braking command.

Furthermore, the ATO over ATBNG Grade of Automation 2 system shall be capable of performing the same functions as ATO over ETCS. However, ATO over ATBNG does not necessarily perform the functions in the same way as ATO over ETCS does.

What information is required for a GoA 2 system, both from track to train and vice versa?

The generic model presents the information which is required for an ATO Grade of Automation 2 system. The ATO system requires five sets of information to execute its function.

1. Safety envelope
2. Timetable
3. Route characteristics
4. Train characteristics
5. Current status of the train

The ATO system provides three sets of information to surrounding systems:

1. Current status of the train
2. Timing point prediction
3. Control commands

Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?

- *What information can ATBNG deliver?*
- *What information should the ProRail traffic management system deliver?*

The ProRail traffic management system must deliver a journey profile and segment profiles to the ATO onboard.

- The journey profile is a description of the timetable.
- The segment profile is a description of the infrastructure

The ProRail traffic management system is currently not equipped to deliver journey and segment profiles to the train. The journey profiles should be updated and automatically sent to the ATO onboard based on interventions made by signal operators. Furthermore, additional information must sent to the train to support non-delayed braking.

ATBNG is equipped to deliver the required information to the ATO onboard system. The ARR protocol can be used to provide the ATO system with ATBNG information.

Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?

The current system is not capable of utilizing the information provided by the ATO GoA 2 system. However, interviews with signal operators show that the timing point predictions and automatic updates of the journey profile can help with their tasks. These functions require modifications to the ProRail traffic management system.

Which concrete steps can be taken towards connecting a future Automatic Train Operation with the Traffic Management System, for Arriva trains on Groningen - Buitenpost?

ATO over ATBNG connected to a traffic management system requires a number of steps to be taken and some challenges to overcome.

- Addition of ATO trackside and ATO onboard to the railway control system.
- Modifications to the ProRail traffic management system in order to provide and the information required by the ATO system.
- Modifications to the ProRail traffic management system in order to present information received from the ATO system to the signal operator/dispatcher.
- The ATO onboard must be capable of determining a trajectory based on the timetable and the ATBNG/NS'54 operational envelope, depending on delayed or non-delayed braking
- An additional driver machine interface must be added to the ATO system capable of informing the driver about the current status of the ATO system

This report is the result of an exploratory study. The findings in this report are therefore mainly hypothesis. Additional research must be done to test these hypothesis.

Samenvatting

De spoorwegen worden geconfronteerd met de uitdaging om tegelijkertijd de capaciteit van het netwerk en de operationele prestaties te verbeteren. Automatic Train Operation (ATO) is een van de technieken die het mogelijk maakt om de capaciteit te vergroten zonder extra spoor. ProRail is een van de partijen die tests uitvoert met ATO. The testen vinden plaats op zowel modern met ETCS uitgerust spoor als op conventioneel spoor uitgerust met NS'54 lichtseinen en Automatische TreinBeïnvloeding Nieuwe Generatie (ATBNG). Een van deze conventionele spoorlijnen is de spoorlijn Groningen-Buitenpost.

Het doel van de ATO testen is om inzicht te krijgen in de voordelen van ATO. De verwachte voordelen zijn onder andere extra capaciteit, reductie van het energiegebruik, en toename van de punctualiteit. Een ander doel is inzicht krijgen in de stappen die vereist zijn om ATO Grade of Automation (GoA) 2[2] te implementeren. Om dit doel te bereiken is het noodzakelijk om testen uit te voeren op het huidige treinbeveiligingssysteem, zoals ATBNG. De literatuur review laat zien dat de specificaties van ATO over ATBNG gedefinieerd zijn, dit is echter niet het geval voor ATO over ATBNG.

Het doel van dit onderzoek is het identificeren van het data verschil tussen ATBNG en ETCS om de testen van ATO over ATBNG mogelijk te maken. Het data verschil moet worden gesloten door alternatieve bronnen te identificeren. Het totale set aan data uitgewisseld tussen alle systemen (trein systemen, ATBNG, en verkeersleiding systemen) moet een volledig beeld geven van de trein, de rail infrastructuur, de route, en de dienstregeling.

De hoofdvraag is:

Welke concrete stappen kunnen er genomen worden om een toekomstig Automatic Train Operation systeem met het verkeersleidingssyteem, voor Arriva treinen op Groningen-Buitenpost?

Ter ondersteuning van het beantwoorden van de hoofdvraag zijn de volgende subvragen opgesteld:

- *Welke functies worden verwacht van een GoA 2 systeem/verkeersleidingssysteem?*
- *Welke informatie is benodigd voor een GoA 2 systeem, zowel van wal naar trein als vice versa?*
- *Is de combinatie van het huidige ProRail verkeersleidingsysteem en ATBNG uitgerust om de voor een ATO GoA 2 systeem vereiste informatie te leveren?*
    - *Welke informatie kan ATBNG leveren?*
    - *Welke informatie moet het ProRail verkeersleidingsysteem leveren?*
- *Is het huidige ProRail verkeersleidingsysteem geschikt om de informatie welke beschikbaar komt door ATO GoA 2 te gebruiken ten behoeven van bijstuuracties?*

[2] Onder Grade of Automation 2 (GoA 2) rijdt de trein automatisch van station naar station. De machinist is echter verantwoordelijk voor het toezien op het veilig rijden van de trein, het sluiten van de deuren, en het besturen van de trein tijdens noodgevallen of verstoringen (UITP, 2012).

De onderzoeksvraag is beantwoord door middel van het opstellen van een conceptueel ATO over ATBNG model. Dit model is in vier stappen ontwikkeld:

1. Ontwikkeling van een generiek ATO model
2. Conceptueel model ATO over ETCS
3. Conceptueel model ATO over ATBNG
4. Validatie van het conceptuele ATO over ATBNG model door middel van drie case studies.

Generiek ATO model

Het ontwikkelde generieke ATO model beschrijft de vereiste input en output data van een ATO systeem. Dit model is onafhankelijk van het type treinbeveiliging ontwikkeld.

Het ATO systeem voert drie functies uit: genereren van een trajectorie, het trajectorie volgen, en het bepalen van tractie/rem commando’s. Het generieke ATO model laat zien dat de functies uitgevoerd door ATO vijf groepen informatie vereist: de veiligheid kader, de dienstregeling, de route karakteristieken, trein eigenschappen, en de huidige status van de trein. Drie sets informatie worden geleverd door het ATO systeem: huidige trein status, voorspelling van toekomstige timing points, en tractie/rem commando’s.

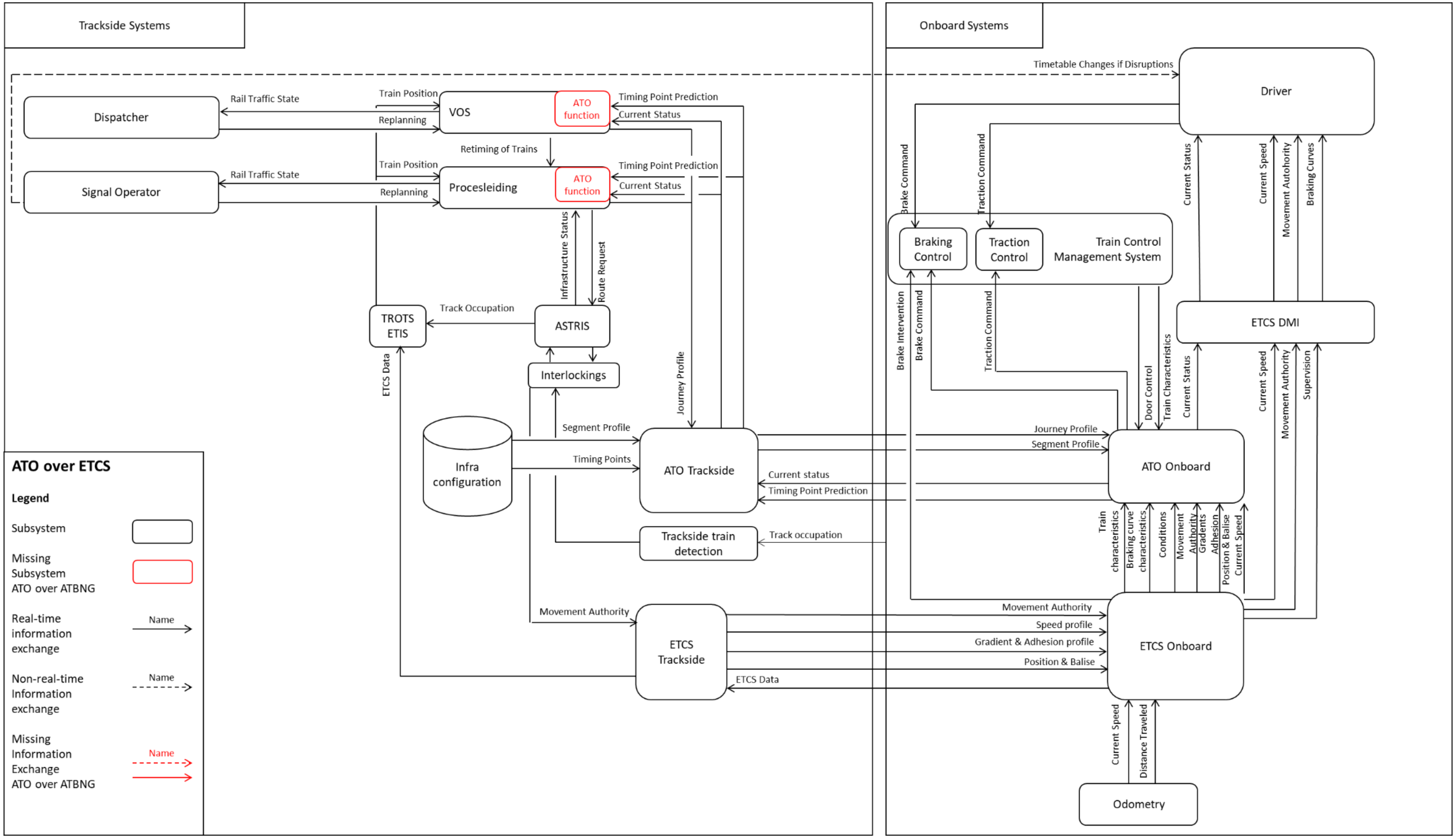
Conceptueel model ATO over ETCS

Het generieke model is gebruikt als onderlegger voor de analyse van ATO over ETCS. Figuur 1 beschrijft het resulterende conceptuele ATO over ETCS SysML model. De subsystemen en informatie uitwisseling tussen de subsystemen zijn gepresenteerd. ATO voegt twee componenten toe aan het spoorsysteem, midden van Figuur 1, de ATO trackside en ATO onboard.

De ATO trackside ontvangt journey profiles (dienstregeling) en segment profiles (infrastructuur beschrijving) van het ProRail verkeersleidingsysteem en stuurt deze naar de juiste ATO onboard. Het ProRail verkeersleidingssysteem moet worden aangepast om deze informatie te kunnen leveren, dit wordt aangegeven door de rode blokken in figuur 1. De ATO trackside ontvangt de huidige status en de voorspelling van toekomstige timing points van de ATO onboard. De voorspelling van toekomstige timing points is de voorspelde aankomsttijd op aankomende punten langs het traject, zoals stations. De huidige status bevat locatie en snelheidsinformatie van de ATO trein. Het ATO trackside systeem stuurt deze informatie naar het ProRail verkeersleidingssysteem. Treindienstleiders geven aan dat deze informatie kan leiden tot een beter situation awareness. Om de informatie te kunnen tonen is een nieuwe functie benodigd binnen het ProRail verkeersleidingssysteem. Deze functie is aangegeven in rood als ATO function (Figuur 1).

De ATO onboard bepaald en verstuurt tractie/rem commando’s gebaseerd op het journey profile, segment profile, de ETCS operationele kader, en de trein karakteristieken. De journey en segment profielen worden ontvangen van de ATO trackside. De ETCS onboard levert parameters waarmee de ETCS operationele kader kan worden afgeleid. De trein zelf, door middel van het Train Control Managment Systeem (TCMS), levert trein karakteristieken. Daarnaast wordt positie informatie geleverd door de ETCS onboard.

De ATO onboard levert informatie aan de ATO trackside, de ETCS onboard, en het tractie/rem systeem. De belangrijkste functie van de geleverde informatie aan de ETCS onboard is het informeren van de machinist door middel van de driver machine interface (DMI) van ETCS. Deze informatie geeft aan of ATO opdracht geeft tot accelereren, uitrollen, of remmen.



Figuur 1 Conceptueel model ATO over ETCS.

Conceptueel model ATO over ATBNG

Het ATO over ETCS conceptueel SysML model is het startpunt voor het conceptuele ATO over ATBNG SysML model. ATBNG neemt de plaats van de ETCS onboard. De ATO onboard moet in staat zijn om de informatie van de ATBNG onboard te interpreteren.

Het SysML model, beschreven in figuur 2, wordt gebruikt om te definiëren welke componenten wijzigen wanneer van men van ATO over ETCS naar ATO over ATBNG gaat. Voor deze componenten is bepaald of de functie gedefinieerd voor ATO over ETCS kan worden uitgevoerd. Daarnaast is bepaald of de vereiste informatie geleverd kan worden door dit component. Als de informatie of functie niet kan worden vervuld wordt een alternatief geïdentificeerd.

De eerste functie uitgevoerd door de ATO onboard is het genereren van een trajectorie. Deze trajectorie is gebaseerd op de relevante operationele kader en het doel gesteld binnen het journey profile. Hier is een probleem gedefinieerd. ATBNG en NS'54 hebben beide een verschillend operationeel kader. NS'54 vereist dat een remming wordt ingezet zodra een sein dat opdracht geeft tot remmen wordt gepasseerd. ATBNG vereist een remming welke past bij de remcapaciteiten van de specifieke trein. Mits de trein beter kan remmen dan de bij NS'54 aangenomen remcapaciteiten zal ATBNG pas later dan het passeren van een sein een remming vereisen. Dit zogenaamde uitgesteld remmen is momenteel niet toegestaan. Het conceptuele model neemt dit dan ook niet mee. Echter ATBNG zelf is niet in staat om de positie van het sein dat opdracht geeft tot remmen door te geven aan de ATO onboard. Deze thesis stelt meerdere opties voor. De meest veelbelovende oplossing is dat het verkeersleidingsysteem extra informatie levert vanuit authentieke bronnen.

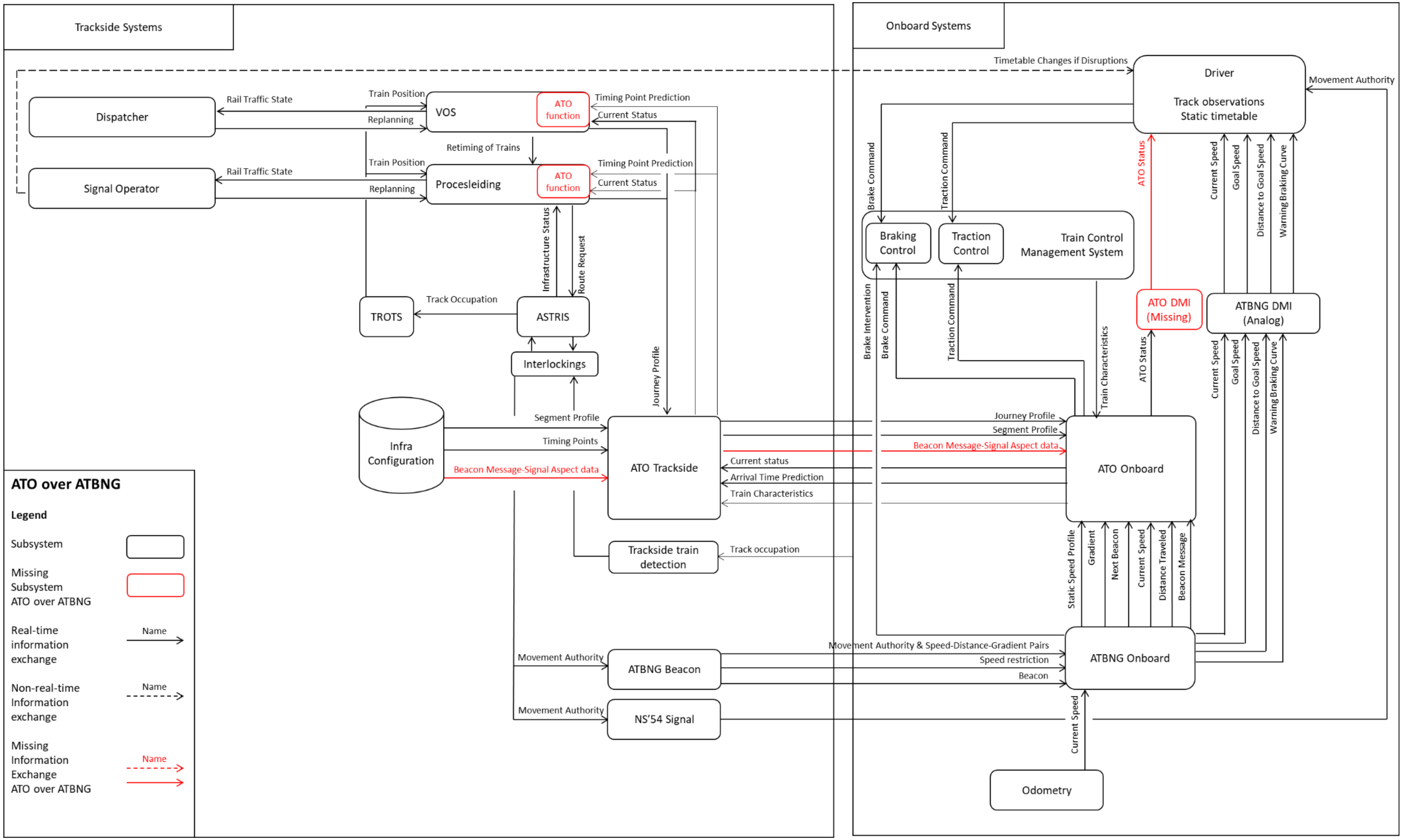
De driver machine interface (DMI) is het instrumentpaneel dat de machinist van informatie voorziet. ATBNG is uitgerust met een specifieke DMI, welke niet in staat is om ATO informatie te tonen. Veranderingen aan de DMI zijn niet gewenst omdat dit onderdeel is van het veiligheidssysteem. Daarom is een extra DMI vereist welke in staat is ATO informatie te tonen.

Een deel van de treinkarakteristieke kan worden geleverd door ATBNG, zoals treinlengte en het aantal geïsoleerde remmen. Overige treinkarakteristieken kunnen worden geleverd door het TCMS of door dit op te slaan in de ATO onboard. ATBNG informatie kan dan worden gebruikt om de juiste karakteristieken te kiezen.

Validatie van het conceptueel model

Het SysML ATO over ATBNG conceptueel model is gevalideerd door middel van drie case studies. De case studies bestaan uit communicatie met verkeersleiding, een rood sein nadering, en een overweg nadering.

De eerste case studie beschrijft een sneltrein welke een enkelsporige stuk spoor oprijdt. Deze wordt gehinderd door een vertraagde stoptrein. Het SysML model is gebruikt om de stappen te analyseren welke vereist zijn om de sneltrein bij te sturen. De analyse is gemaakt voor de huidige, ATO over ETCS, en ATO over ATBNG situatie. Het beschrijven van de stappen maakt het mogelijk om te identificeren welke nieuwe informatie beschikbaar komt vanuit ATO, zoals de voorspelling van de aankomsttijd op timing punten. De analyse geeft de volgende bevindingen. Het huidige systeem ondersteund deze specifieke bijstuuractie niet. De huidige systemen bieden hiervoor beperkte ondersteuning. De case laat zien dat met ATO extra informatie beschikbaar komt voor treindienstleiders bestaande uit voorspelde aankomsttijden en automatische updates van de journey profiles. Interviews met treindienstleiders geven die indicatie dat dit treindienstleiders helpt bij bijstuuracties.



Figuur 2 Conceptueel model ATO over ATBNG.

De tweede case studie is een rood sein nadering. Het conceptuele SysML model is gebruikt om de stappen te bepalen die een ATO trein doorloopt om te bepalen dat een sein rood is en een remming in te zetten. Aan elke stap is een tijd gehangen, de hiervoor gemaakte aannames staan beschreven in paragraaf 7.3.1. Gebaseerd op de tijd die het proces vereist is de afstand tot het rode sein bepaald waar het seinbeeld bekend moet zijn. Deze eerste berekeningen laten zien dat een rood seinbeeld voldoende vroeg bekend is vanuit een veiligheids perspectief. Echter vanuit operationeel perspectief zijn er mogelijke problemen geconstateerd. Bij hogere baanvak snelheden moet het seinbeeld voor de minimale blokafstand bekend zijn. Dit kan ertoe leiden dat seinbeeld verbeteringen pas na het inzetten van een remming verwerkt worden. Dit leidt tot remmingen die niet noodzakelijk zijn. Het optreden van dit probleem is afhankelijk van de baanvak snelheid en de plaatsing van ATBNG bakens.

De derde case studie is een overweg nadering. Het SysML model laat zien dat de ATO onboard geen informatie ontvangt welke het mogelijk maakt om te bepalen of de overweg vrij is. De machinist is verantwoordelijk om te bepalen dat de overweg vrij is. Echter met ATO is deze taak niet langer onderdeel van een actieve besturingstaak maar van een controlerende taak. Literatuur laat zien dat dit mogelijk leid tot het Out of The Loop probleem waarbij de reactie tijd kan toenemen.

Conclusie

Het volgende kan worden geconcludeerd wat betreft de onderzoeksvragen:

Welke functies worden verwacht van een GoA 2 systeem/verkeersleidingssysteem?

Het generieke ATO model beschrijft drie functies voor het ATO systeem: genereren van een trajectorie, het trajectorie volgen, en het bepalen van tractie/rem commando’s.

Daarnaast wordt verwacht dat het ATO over ATBNG GoA 2 systeem in staat is om dezelfde functies als ATO over ETCS kan uitvoeren. Echter niet perse op dezelfde manier als ATO over ETCS.

Welke informatie is benodigd voor een GoA 2 systeem, zowel van wal naar trein als vice versa?

Het generieke ATO model presenteert de informatie welke vereist is voor een ATO GoA 2 systeem. Het ATO systeem vereist vijf sets aan informatie om zijn functie uit te voeren:

1. Veiligheid kader
2. Dienstregeling
3. Route karakteristieken
4. Trein karakteristieken
5. Huidige status van de trein

Het ATO systeem levert drie sets aan informatie aan omliggende systemen:

1. Huidige status van de trein
2. Voorspelling van toekomstige timing points
3. Tractie/rem commando’s

Is de combinatie van het huidige ProRail verkeersleidingsysteem en ATBNG uitgerust om de voor een ATO GoA 2 systeem vereiste informatie te leveren?

- o *Welke informatie kan ATBNG leveren?*
- o *Welke informatie moet het ProRail verkeersleidingsysteem leveren?*

Het ProRail verkeersleidingssysteem moet journey en segment profiles leveren aan de ATO onboard.

- Het journey profile beschrijft de dienstregeling
- Het segment profile beschrijft de infrastructuur

Het ProRail verkeersleidingsysteem is momenteel niet in staat om journey en segment profiles aan de ATO onboard. Het journey profile moet worden geüpdatet gebaseerd op bijstuuracties van treindienstleiders. Daarnaast moet extra informatie worden geleverd aan de ATO onboard t.b.v niet-uitgesteld remmen.

ATBNG is geschikt om informatie te leveren aan de ATO onboard. Het ARR protocol kan hiervoor gebruikt worden.

Is het huidige ProRail verkeersleidingsysteem geschikt om de informatie welke beschikbaar komt door ATO GoA 2 te gebruiken ten behoeven van bijstuuracties?

Het huidige systeem is niet in staat om de informatie welke ATO levert te gebruiken. Echter, interviews met treindienstleiders laten zien dat de voorspelling van toekomstige timing points en het automatisch updaten van het journey profile kan helpen bij hun taken. Deze functies vereisen aanpassingen aan het ProRail verkeersleidingssysteem.

Welke concrete stappen kunnen er genomen worden om een toekomstig Automatic Train Operation systeem met het verkeersleidingssyteem, voor Arriva treinen op Groningen-Buitenpost?

ATO over ATBNG verbonden met het ProRail verkeersleidingssysteem vereist een aantal te nemen stappen.

- Toevoeging van een ATO trackside en ATO onboard aan het spoorsysteem
- Aanpassingen aan het ProRail verkeersleidingssysteem welke het mogelijk maakt om informatie te leveren aan het ATO systeem
- Aanpassingen aan het ProRail verkeersleidingssysteem welke het mogelijk maakt om de informatie geleverd door ATO te tonen aan treindienstleiders/decentrale verkeersleiders
- De ATO onboard moet in staat zijn om een trajectorie te genereren gebaseerd op de dienstregeling en de ATBNG/NS’54 operationele kader, afhankelijk van niet-uitgesteld of uitgesteld remmen
- Een extra ATO DMI is vereist welke in staat is om de machinist te informeren over de huidige status van het ATO systeem.

Dit rapport is het resultaat van een verkennende studie. De bevindingen zijn daarom voornamelijk hypotheses. Extra studies om deze hypotheses te testen zijn vereist.

Glossary

ASTRIS	Aansturing en Statusmelding van de Railinfrastructuur
ATBNG	Automatische Treinbeïnvloeding Nieuwe Generatie
ATBEG	Automatische Treinbeïnvloeding Eerste Generatie
ATBVV	Automatische Treinbeïnvloeding Verbeterde Versie
ATO	Automatic Train Operation
ATO-OB	Automatic Train Operation On Board system
ATO-TS	Automatic Train Operation Trackside System
ATO-States	
• NP	ATO No Power
• CO	ATO Configuration
• NA	ATO Not Available
• AV	ATO Available
• RE	ATO Ready
• EG	ATO Engaged
• DE	ATO Disengaging
• FA	ATO Failure
ATP	Automatic Train Protection System
ARR	Automatische Rit Registratie: a communication protocol by which the ATBNG onboard sends its status to the judicial recorder unit
Block Section	Jörn Pachl (2018): "A section of track in a fixed block system, which a train may only enter if the section is not occupied by other vehicles."
DAS	Driver Advisory System
• C-DAS	Connected Driver Advisory System
• S-DAS	Standalone Driver Advisory System
• N-DAS	Networked Driver Advisory System
Delayed braking	Braking according to the ATBNG braking curve
Non-delayed braking	Braking according to the NS'54 braking curve
DIS	Driver Information System
DSP	Dynamic Speed Profile
ERA	European Agency for Railways
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GoA	Grade of Automation
JP	Journey Profile
JRU	Juridical Recorder Unit
MRSP	Most Restrictive Speed Profile
Open Track	Track section between station areas
OTMR	On-Train Monitoring Recorder
SBG	Spoor Bezettings Grafiek
SFERA	Smart Communications For Efficient Rail Activities
Situation Awareness	Mica Endsley (1995): "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future."
SP	Segment Profile
SSP	Static Speed Profile
TCMS	Train Control Management System
TMS	Traffic Management System
TIM	Train Integrity Module

TROTS	Trein Observatie & Tracking Systeem

1. Introduction

Railways are facing a challenge to simultaneously increase the capacity and the operational performance of their network. However, adding capacity by adding track is ever more difficult due to limited space in urban areas (ProRail, 2018a). Therefore, ways must be found to reliably and safely utilize more of the existing railway infrastructure. Multiple possibilities exist to increase track capacity. One such technology, Automatic Train Operation (ATO), is already common practice on metro systems around the world. Developments are taking place to bring ATO to mainline railways.

One of the parties testing developments in ATO is ProRail (ProRail, 2018b). Not only does ProRail test ATO on state of the art, ETCS (European Train Control System) equipped, railway lines (e.g. Betuweroute), tests on conventional, ATBNG (Automatische TreinBeïnvloeding Nieuwe Generatie) equipped, railway lines (e.g. Groningen-Leeuwarden) are performed as well.

The focus of this research is on ATO Grade of Automation (GoA) 2 over ATBNG between Groningen-Buitenpost-(Leeuwarden). Currently (2019), ProRail and its partners are testing ATO GoA 2 over ATBNG. The test in Groningen is executed in three phases (ProRail, 2018c):

1. Automation of train movements with green signals only.
2. ATO with simulated track occupancy, ATO interface with ATBNG required.
3. Connection between ATO ATBNG, and the Traffic Management System

The aim of the test with ATO is to get insight in the advantages of ATO. The advantages are expected to be, among others, an increase of capacity, reduction of energy use and an increase of punctuality. Furthermore, safety must not be adversely impacted and should preferably be improved. Another goal of the test is to gain insight in the steps which are needed to implement ATO GoA 2. To achieve this goal it is necessary to test ATO on the current automatic train protection system, such as ATBNG.

The first two phases of the ATO trial in Groningen are underway. However additional research must be done to allow for phase 3.

The introduction of ATO requires an information exchange between the train, the ProRail Traffic Management System (TMS), and the Automatic Train Protection system (ATP). On ETCS equipped railway lines much of this information is provided by the ETCS system. However, the Groningen-Leeuwarden railway line is not equipped with ETCS but with ATBNG. There is a difference in the information ATBNG can provide compared to ETCS. Information must therefore be provided by other systems as well.

1.1 Research Questions

The objective of this research is to identify the data gap between ATBNG and ETCS, to support the tests of ATO over ATBNG. The data gap must be closed by identifying sources within other systems. A conceptual ATO over ATBNG model is developed which describes the information exchange within the ATO over ATBNG system and requirements for ATO over ATBNG. The total set of information exchanged between all the systems (train side systems, ATBNG, and Traffic Management Systems) must provide a complete picture of the train, the rail infrastructure, the route, and the timetable.

The main research question is:

Which concrete steps can be taken towards connecting a future Automatic Train Operation with the Traffic Management System, for Arriva trains on Groningen - Buitenpost?

The focus of the research is on the data stream between train, TMS, ATO, and ATBNG. An ATO GoA2 system requires certain information from the traffic management system. However, the system also provides more detailed information about the state of the train (location, speed, etc.). This results in the following four sub-questions.

- *What functions are expected from the GoA 2 system/ Traffic Management System?*

- *What information is required for a GoA 2 system, both from track to train and vice versa?*

- *Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?*
    - *What information can ATBNG deliver?*
    - *What information should the ProRail TMS system deliver?*

- *Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?*

1.2 Methodology

This section briefly presents the method followed in this master thesis. The master thesis has been divided into four phases. Each phase answers specific research questions, which have been indicated below.

- **Phase 1 Literature review**
  The literature review identified the expected functions from the ATO GoA 2 system and the traffic management system, the data requirements, system architectures of ATO over ERTMS and SFERA, the data ATO provides, and the capabilities of the ProRail traffic management system. The literature review provides a further understanding of the problem and the current state of the art.

- **Phase 2 Development of generic ATO model**
  The generic ATO model describes the various components of the ATO system. Both the input information and the output information of the ATO onboard are discussed. Furthermore, a first validation is done by mapping ATO over ETCS on this generic ATO model. Answering the following research questions:

  What functions are expected from the GoA 2 system/ Traffic Management System?
  What information is required for a GoA 2 system, both from track to train and vice versa?

- **Phase 3 Mapping of generic ATO model on ATO over ATBNG**
  ATO over ATBNG is mapped onto the generic model. The data gap of ATO over ATBNG is identified. Furthermore, possible solutions to solve the data gap are presented. Resulting in a conceptual model of ATO over ATBNG. Answering the following research question:

  Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?
    - *What information should ATBNG deliver?*
    - *What information should the ProRail TMS system deliver?*

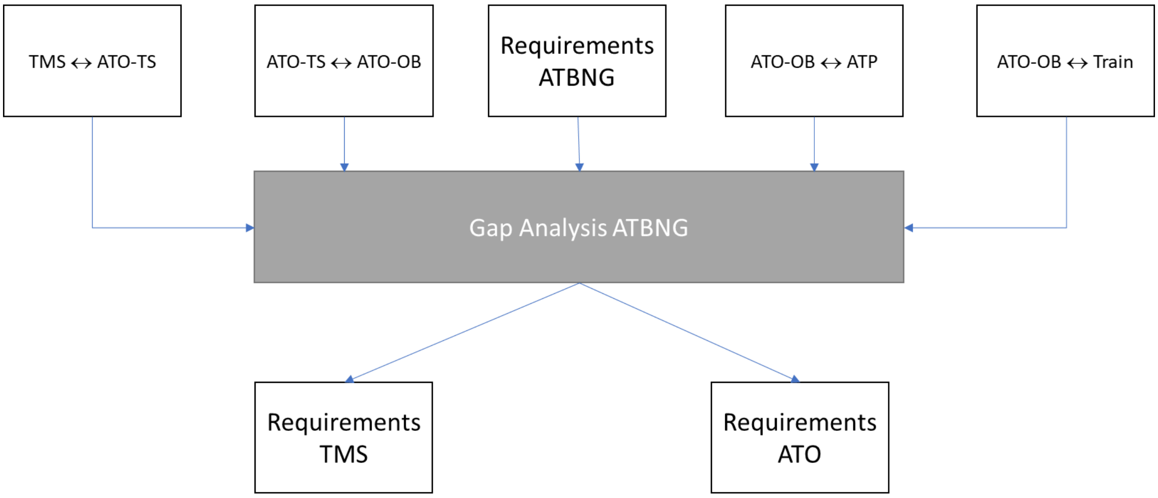


Figure 3 Methodology followed in this master thesis.

- **Phase 4 Validation of the ATO over ATBNG model**
  During this phase of the research, use cases are studied using the ATO over ATBNG model which has been developed in previous phases. First a set of cases is developed. The cases are written down as a scenario. Each scenario is then worked through using the ATO over ATBNG model.

  Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?

  Which concrete steps can be taken towards connecting a future Automatic Train Operation with the Traffic Management System, for Arriva-Trains on Groningen - Buitenpost?

1.3 Reading Guide

Chapter 2 presents a review of the literature discussing Automatic Train Operation, the integration of Automatic Train Operation and real time traffic management, Automatische Treinbeïnvloeding Nieuwe Generatie, and the safe envelope conceptual model.

Chapter 3 presents an introduction into the railway control, command, and signalling system. The Automatic Train Operation system will be placed within the control, command, and signalling system. It is therefore essential to have an unambiguous understanding of various systems within the control, command, and signalling system. Readers familiar with the railway system can skip this chapter.

Chapter 4 presents a generic conceptual model of the ATO system. This model describes the input, function, and output of the ATO system, irrespective of underlying traffic management and automatic train protection system. The model is used further on in the report as a framework to discuss ATO over ETCS and ATO over ATBNG. Answering the following subquestion:

- *What information is required for a GoA 2 system, both from track to train and vice versa?*

Chapter 5 discusses ATO over ETCS including the functional requirements and the system architecture. The chapter concludes with a conceptual ATO over ETCS model. This model describes the various components of ATO over ETCS and the information exchanged between the various components. The following subquestions are answered:

- *What functions are expected from the GoA 2 system/ Traffic Management System?*

Chapter 6 presents an analysis of ATO over ATBNG according to the structure provided by the generic conceptual model. The conceptual ATO over ETCS model is translated into an ATO over ATBNG model. Data gaps between ATO over ATBNG and the required data as identified by comparison with the generic conceptual model and the conceptual ATO over ETCS model are stated. The resulting conceptual model of ATO over ATBNG is presented. Answering the following sub question:

- *Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?*
    - *What information should ATBNG deliver?*
    - *What information should the ProRail TMS system deliver?*

Chapter 7 presents the validation of the conceptual model of ATO over ATBNG as is presented in chapter 6. Cases, chosen based on desired functions, are worked through using the conceptual model. The cases are worked out in scenario's and worked through step by step using the conceptual model. For each step the required information and the orgin of the information are stated. The case considering traffic management is particularly relevant as it answers the following research question:

- *Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?*

Chapter 8 presents the conclusions and recommendations resulting from this research.

2. Literature Review

This chapter presents the literature reviewed for this master thesis research.

First literature on the topic of automatic train operation is discussed in section 2.1, the developments of both urban and mainline railways are discussed. Moreover, some attention is given to the topic of driver advisory systems and energy efficient driving. Secondly, literature proposing an integration of automatic train operation and real-time traffic management systems is discussed. Thirdly, the topic of *"Automatische TreinBeïnvloeding Nieuwe Generatie"*, the ATBNG automatic train protection system is discussed. Section 2.4 discussed the envelope of safe operation model. This chapter is concluded with small discussion of the concept of situation awareness presented in section 2.5.

2.1 Automatic Train Operation

A large amount of literature is available on the topic of Automatic Train Operation (ATO). Besides developments in urban railways momentum for ATO on mainline railways is picking up. This momentum can be seen in the development of specifications for ATO over the European Train Control System (ETCS) and real world trials of ATO.

The main potential benefit of ATO identified in literature (Roa, et al., 2016), (Di Claudio et al., 2014), is the ability to closely follow a predetermined trajectory. This allows for a higher punctuality by more precise execution of the timetable, a higher utilization of available capacity by reducing the need for running time supplements, and energy efficient operation by following a trajectory optimized for energy efficient usage.

2.1.1 Automatic Train Operation in Urban Railways

Urban railways are ahead in the development of ATO, with several unattended trains already in operation (UITP, 2012). Several papers discuss the topic of ATO on urban railways (Di Claudio et al., 2014), (Yin et al, 2017).

Yin et al. (2017) identify a number of functions which can be executed by the ATO system. First, the train must run automatically between stations, precisely stopping at a defined stopping point. Furthermore, additional functions can be identified such as the operation of platform doors and automatic train reverse.

The system architecture of automatic train operation in urban railways consists of three subsystems (Di Claudio et al., 2014), (Yin et al., 2017).

1. The Automatic Train Supervision (ATS) system manages the train traffic, including train routing, conflict detection, and conflict resolution. Literature is not clear if the interlocking function, which ensures only safe routes are set, is integrated in the ATS system or if this is a separate system. The ATS system provides the ATO system with the movement authority, travel direction and destination information.

2. The Automatic Train Protection (ATP) performs the safety critical function of enforcing the movement authority. The distance of the train is authorized to travel is enforced by a braking intervention. The ATP system provides information on speed limits, current speed, and current position. Stopping precisely might require additional points of information exchange close to the stopping location.

3. The Automatic Train Operation (ATO) system manages the non-safety critical function of running the train by controlling the brake and traction systems. Further operational

systems can also be automated by the ATO system, such as door operation and train setup.

2.1.2 Developments in Automatic Train Operation in Mainline Railways

Current research is mainly on the topic of ATO over ERTMS (Goverde & Theunissen, 2018). However, full ERTMS coverage is not expected until 2050 (Rijksoverheid.nl, 2019). Furthermore, capacity problems already exist on railway lines which are not soon to be equipped with ERTMS (Ministerie I&W, 2018). These railway lines include Groningen-Leeuwarden and Nijmegen-Roermond. This issue has been identified before and the feasibility of ATO over ATB was studied (Goverde & Theunissen, 2018). An important conclusion of this study is the identification of ATO over ATBNG as most promising given the safety gaps present in both ATBEG and ATBVV.

SNCF, the French national railway company, presented their vision on Automatic Train Operation (ATO) in 2018 (Lagay & Adell, 2018). Similar as the system architecture of ATO for urban railways SNCF identifies the need to separate the safety critical function (ATP) and the non-safety critical function (ATO). SNCF identified that the current development of ATO focusses on ATO over ETCS. However, there is a transition period from legacy Automatic Train Protection systems to ETCS, thus SNCF is exploring ATO over existing French ATP systems. Furthermore, SNCF stresses the need for a standardized solution ensuring the ATO components of different vendors are interchangeable.

ATO over ETCS

The development of specifications for ATO over the European Train Control System (ETCS) has started. The principles of ATO over ETCS and the specifications are laid down in a number of documents, the main documents are:

- ATO over ETCS Operational Principles (ERTMS Users Group, 2017a)
- ATO over ETCS Operational Requirements (ERTMS Users Group, 2017b)
- Subset-125 ATO over ETCS - System Requirement Specification (UNISIG, 2018a)
- Subset-126 ATO over ETCS - ATO-OB - ATO-TS interface specification (UNISIG, 2018b)
- Subset-130 ATO over ETCS - ATO-OB - ETCS interface specification (UNISIG, 2018c)
- Subset-139 ATO over ETCS - ATO-OB – Vehicle interface specification (UNISIG, 2018d)

The development of ATO over ETCS standards is performed within Shift2Rail, Innovation Programme 2. Furthermore, the European Union Agency for Railways (ERA) is the system design authority for the standard (ERA, n.d.) to be developed. In this capacity it must agree with the ATO over ERTMS architecture and the interface standard.

The operation principles (ERTMS Users Group, 2017a) state that the ATO over ETCS system is made up of two subsystems. These subsystems are the ETCS system and the ATO system. A clear choice is made, the ATO system is a non-safety critical system. Safety functions are assigned to a safety critical system such as ETCS. The ATO Onboard operates the train automatically, controlling both traction and braking. This approach is similar to the approach taken in urban railways.

Furthermore, two interfacing systems are identified. Firstly, the train system which executes the commands produced by the ATO subsystem. Secondly, the ATO trackside system, which interfaces with the Traffic Management System.

Another important principle defined in the operational requirements for ATO over ETCS (ERTMS User Group, 2017b) is interoperability. ATO Onboards (OB) and ATO Tracksides

(TS) of different suppliers shall be interoperable. However, this interoperability is only applicable for the highest grade of automation supported by both the ATO-OB and ATO-TS. For example, an ATO-TS capable of GoA 3 and an ATO-OB capable of GoA 4 default to GoA 3.

2.1.3 Driving Advisory Systems

Driver Advisory System (DAS) can aid the precise execution of the timetable. Furthermore, the information required for a DAS system is similar to the information required for ATO. Therefore, literature on DAS is taken into account in this literature review.

Panou et al. (2013) revealed a clustering of DAS systems connected to the Traffic Management System (C-DAS). The clustering was initially presented in the On-Time (On-Time, 2013a) project and used in the development of the SFERA standard (Lima-Vanzeler, 2018).

Central C-DAS systems centralize the chain of computation in the TMS system. The calculation of the optimal speed profile and the corresponding advice is performed by the TMS system. The calculations are based on a known train path envelope.

Intermediate C-DAS systems distribute the chain of computation. The calculation of the optimal speed profile, corresponding to the known train path envelope, is performed by the TMS system. The calculation of the corresponding advice is performed in a trainside system.

Onboard C-DAS systems centralize the chain of computation inside the train. The traffic management system sends the train path envelope to a trainside system which calculates the optimal speed profile and advice.

Two other types of DAS are identified in literature. These types are not defined according to the division of calculation task but refer to the way the advice is generated in real-time. Standalone DAS (S-DAS) generates its advice based on a predetermined trajectory and the actual deviation from this trajectory. Networked DAS (N-DAS) allows for updates to be sent from the traffic management system to the train, however, this is not necessarily in real time.

2.1.4 Energy Efficient driving

A large number of literature mentions potential energy savings by implementing an ATO system which follows an optimized driving strategy (Yin et al., 2017), (Scheepmaker et al., 2017).

For this research the focus is on the information required for a function which would provide an optimal trajectory, from an energy perspective, for the ATO system. Scheepmaker et al, (2017) present a review which discusses the development of various models and solution methods to find an optimal driving strategy. Two subsets of variables are identified for determining the optimal driving strategy.

- Train characteristics including tractive/braking force, resistance and the current status (position, speed, acceleration).
- Track characteristics including gradient resistance, speed limits, and the electrification system. An analysis performed by Van Dongen and Schuit (1989) on energy efficient driving in the Netherlands shows that accelerating at less than maximum acceleration is beneficial due to the low voltage (1500 V) electrification system. Thus, the specifics of the electrification system influence the energy efficient driving strategy on electric railways.

However, a function which optimizes the driving strategy of the train is not a prerequisite for the implementation of ATO. Furthermore, ATO itself is also not required for the implementation of an optimal driving system. A Driver Advisory System (DAS) can support the driver with an advise to achieve the optimal driving strategy without automating the driving function itself.

2.2 Integration of ATO and real-time railway control

A topic of recent research is the integration of both ATO and real-time traffic management. Railway operation is a superimposition of two feedback loops (Luthi, 2009). (i) An outer feedback loop which supervises and manages railway traffic. Within the outer loop deviations and conflicts are detected, a new schedule is determined and sent to the train. (ii) The inner feedback loop concerns the train itself. Within this loop a trajectory is generated to achieve the new schedule, the trajectory is updated based on the current status of the train.

A recent study by Rao et al. (2016) presents a proposal to integrate traffic management and train automation. It is identified that current optimization, by automated systems, is primarily focused on either one of the two feedback loops.

Two types of systems focus on the optimization of the outer feedback loop. The first system is the Decision Support System. According to Rao et al. (2016) *"Decision Support Systems (DSS) focuses on resolving traffic conflicts by generating control advises (reordering, rerouting, or retiming of trains) to the dispatcher."* Thus, railway traffic is optimized by advising the dispatcher on how to resolve conflicts between trains in an optimal manner. The second system is the aforementioned connected driver advisory system. Rao et al., (2016) mention that DAS-C is currently seen as a supplement to DSS systems.

Standalone driver advisory systems (S-DAS) and ATO focus on the optimization of the inner control loop. Either advising the driver on how to adhere closely to the trajectory or by a system which automatically adheres to the trajectory.

Rao et al. (2016) propose to combine the optimization of the outer loop (traffic management) and the inner loop (train control). The proposed TMS requires a conflict detection and conflict resolution function. The TMS calculates target points such that if a target point is achieved a train can pass a conflict with a minimum travel time. The ATO system is then tasked with the precise execution of this trajectory, by calculation of the optimal traction and braking commands.

Quaglietta et al. (2016) propose a framework for real-time traffic management making use of a web based Service-Oriented Architecture and standardized railML interfaces. The developed software framework integrates algorithms for traffic state monitoring, prediction, track and connection conflict detection, automatic route setting, and a driver advisory system. Individual modules of the framework contain one of the aforementioned algorithms. Data to be transferred between modules are considered events. The event-dispatcher collects the data from modules which publish a certain event and distribute it to modules which subscribe to an event.

Information about the traffic state is delivered to the Traffic State Monitoring module, which outputs the current traffic state. The Perturbation Management Module is the core of the framework and performs Traffic State Prediction, Conflict Detection and Resolution, and Connection Conflict Detection Resolution. The output of the Perturbation Management Module is an optimal Real Time Traffic Plan. The Real Time Traffic Plan can be automatically implemented by an Automatic Route Setting module.

Furthermore, the Train Path Envelope Computation module can calculate the buffer times which can be exploited for energy efficient driving from the Real Time Traffic Plan. An energy efficient speed-distance trajectory can then be calculated by the Driver Advisor System module.

2.3 Automatische Treinbeïnvloeding Nieuwe Generatie

Automatische Treinbeïnvloeding Nieuwe Generatie (ATBNG, Automatic Train Protection New Generation) is an Automatic Train Protection (ATP) system installed on a number of regional railway lines in the Netherlands. Groningen – Leeuwarden is one of the railway lines equipped with this ATP system (ProRail, 2019a).

Because NS (Nederlandse Spoorwegen) reached the limitations of Automatische Trein Beïnvloeding Eerste Generatie (ATBEG), (Van Leur, 1994). ATBNG was developed to improve upon the safety functions provided by ATBEG. Furthermore, it allows for an increase in quality of service by removing some of the limitations imposed by ATBEG. Van Leur (1994) presents the following summary of the main safety and quality of service features:

- Train stop function, when a signal at danger is passed.
- Braking curve supervision based on individual train characteristics.
- Full in- cab signaling.
- Speed-distance profile sent by beacons.
    - Static speed profile with small speed steps (10 km/h).
    - Possibility to input temporary speed restrictions.
    - Release speed in front of signals at danger allowing trains to reach the beacon.

2.4 Conceptual Model: Envelope of Safe Operation

Safety is an important aspect of Automatic Train Operation (ATO). The choice has been made to discuss the safety aspect of ATO according to the envelope of safe operation. This conceptual model allows to take into account both the concept of safety and quality of service. Both concepts coincide nicely with the aim of ATO.

The concept of the envelope of safe operation originates with Rasmussen (1997). The model proposed by Rasmussen is developed from an organizational point of view. One interesting notion of Rasmussen is that in a competitive environment companies tend to move towards the boundary of the safe area as this yields a competitive advantage. Hale et al. (2007) further developed the model from a more operational point of view.

Van den Top (2010) further developed the envelope of safe operation model. The concept of quality of service is added to the model by defining a goal state. Four envelopes are defined within the envelope of safe operation model. First, the viable envelope, encompassing all system states in which no damage occurs. Second, the controllability envelope which consists of all the system states for which effective control to prevent damage exist. Third, the operational envelope, which includes all system states deemed acceptable by relevant organizations. The goal can be captured in an operational envelope, for example the timetable can be an operational envelope. Van den Top (2010) mentions “not all higher-level functions (e.g. timetable design and infrastructure design) use the same acceptability criteria (e.g. different variables and/or different boundaries per variable), there can exist different operational envelopes.” Last, the attainable envelope which can be reached within a specific time step. Figure 4 shows the envelopes defined within the safe envelope of operations model on a rather generic railway case.

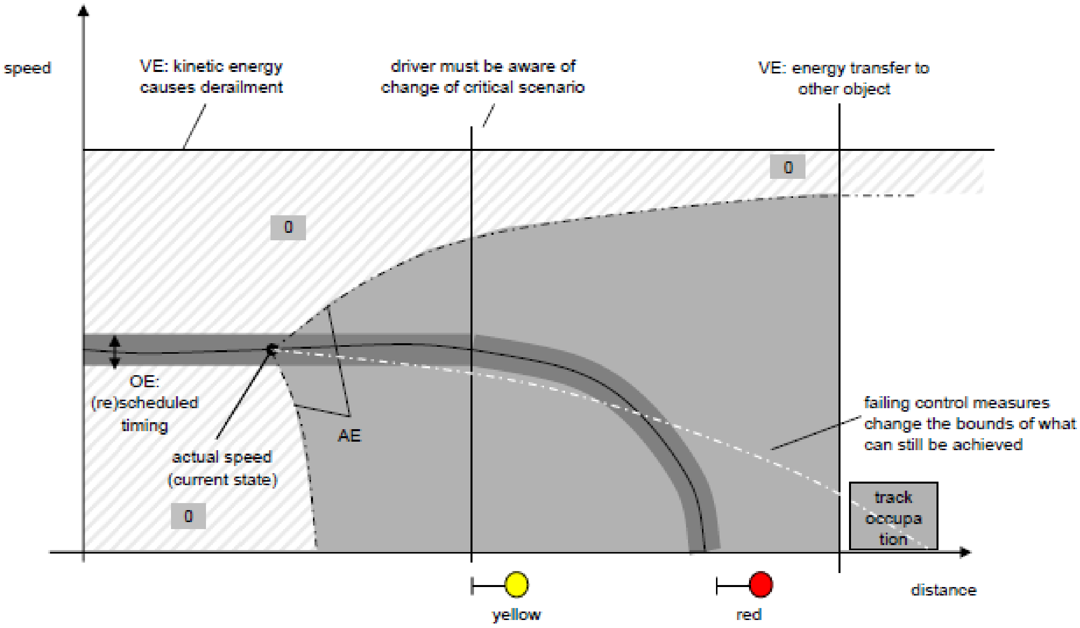


Figure 4 Envelopes defined within the safe envelope of operations model (Van den TOP, 2010). VE: Viable Envelope. Controllability Envelope not shown. OE: Operational Envelope. AE: Attainable Envelope.

Hale et al. (2007) identified a safety margin between the controllability envelope and operational envelope System states which are located between the controllability envelope and the operational envelope are not deemed acceptable, however effective measures to bring the system state within the operational envelope exist. This allows an operator to identify the unacceptable state and take measures to bring the system back to the operational envelope.

Lastly, a goal state and actual state are defined. These states relate to the quality of service concept included in the envelope of safe operation model. The goal state is the desired state within the operational envelope.

Sections 5.2.2 and 6.4.1 discuss the application of the safe envelope of operation model onto ATO over ETCS and ATO over ATBNG.

2.5 Situation Awareness

The concept of situation awareness is often mentioned in the context of automation and the design of automated systems (Endsley & Kiris, 1995), (Endsley, 1995).

Endsley (1995) presents the following general definition of situation awareness: “Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.”

Automation can impact situation awareness adversely (Endsley & Kiris, 1995). This can result in the out of the loop problem whereby response times increase when automation fails.

3. The Railway Control, Command, and Signalling System

This chapter presents an overview of the system architecture of the railway control system. This background information is required to understand the development of the generic ATO model, the developed ATO over ETCS conceptual model, and the analysis of ATBNG presented in chapters 4,5,and 6.

The first section presents a generic overview. Section 3.2 presents a generic system architecture of the railway control system. ATO is added to this generic system architecture. The specifics of ATO over ETCS and Class-B/SFERA are discussed in sections 3.3 and 3.4 respectively. Section 3.5 discusses the ProRail traffic management system.

3.1 Generic System Architecture of the Railway Control System

Understanding of the generic system architecture of the railway control system is essential for identifying the changes and data exchanges required for ATO over ATBNG.

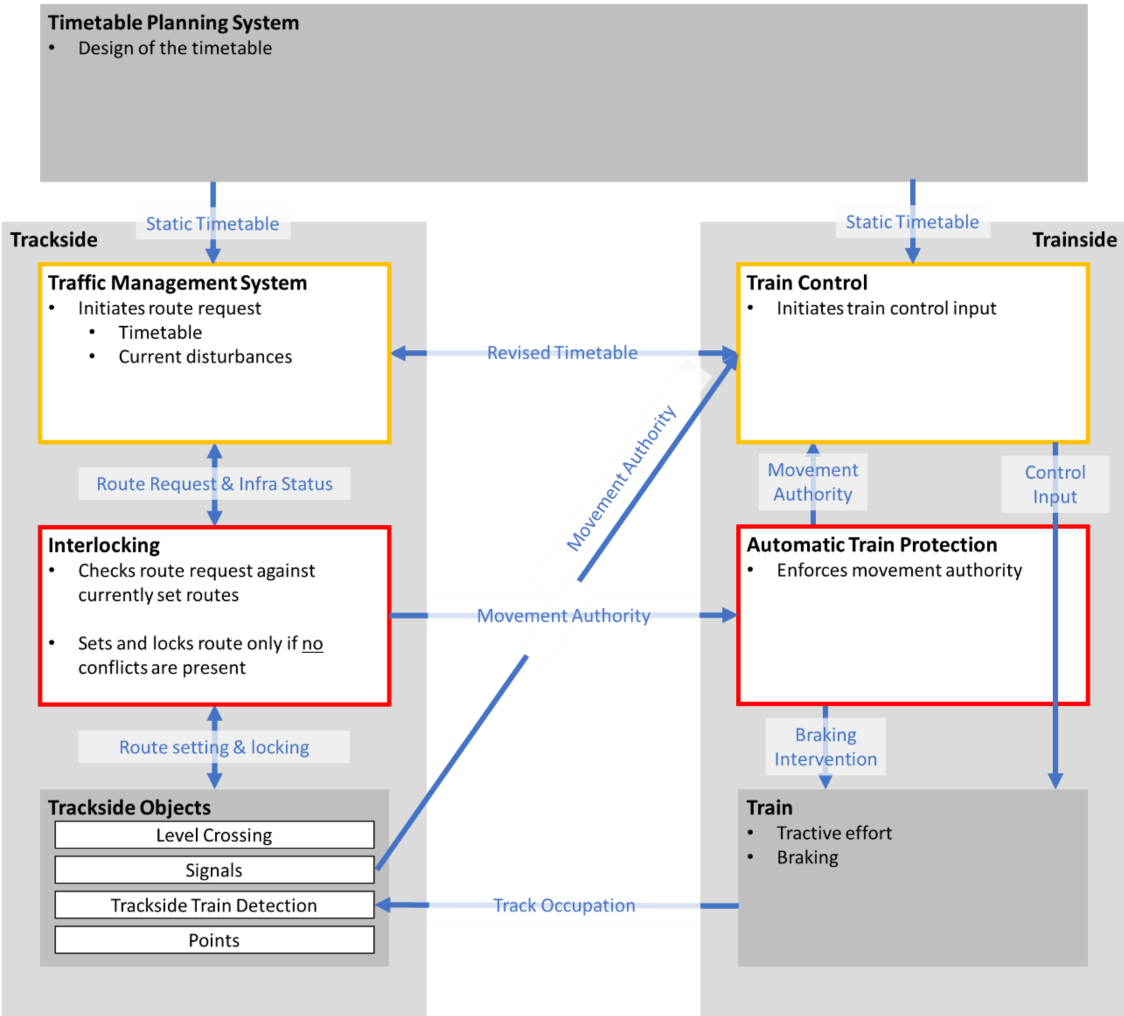


Figure 5 Generic system architecture railway control system.

Figure 5 presents the generic system architecture. The dark gray block on top depicts the timetable planning system. The light gray block on the left depicts the trackside systems and the light gray block on the right depicts the train side system.

3.1.1 Timetable Planning System

The timetable planning system is used to design the timetable. The design is based on customer demands and constraints of infrastructure capacity, rolling stock planning, and staff planning. The timetable presents the arrival and departure times and the passing times of junctions, so called Dienstregelpunten (timetable points).

This timetable is provided to the traffic management system and the driver of the train.

3.1.2 Traffic Management System

The traffic management system initiates route request based on the timetable. In undisturbed operation route requests will often be initiated by an Automatic Route Setting (ARS) system.

The traffic management system also intervenes whenever railway traffic is disturbed. Often traffic management is divided in multiple layers (Schippers & Gerrits, 2018). One layer (dispatchers) makes interventions on a network wide level such as train cancelations or rerouting of trains, the corresponding changes on the local level are made by a second layer (signallers). Signallers make interventions on a local scale, changing the sequence of trains or changing the route a train takes through the station area.

Route request either originating from an ARS system or a signaller are sent to the interlocking. Furthermore, changes to the timetable are communicated to the train by voice communications.

3.1.3 Interlocking

The interlocking is a safety critical system. It ensures the conflict free setting of routes. Routes requested by traffic management are set if and only if no conflicting routes are currently set.

If no conflicts are present the interlocking will set trackside objects in the correct position and sent a movement authority to the driver (using a trackside signal) and the automatic train protection (using coded track circuits or radio beacons in the track).

Furthermore, the interlocking will report back the status of the rail infrastructure to the traffic management system.

3.1.4 Trackside Objects

A multitude of trackside objects are present. These include:

- level crossings
- signals which indicate the movement authority to the driver
- Automatic Train Protection beacons which sent the movement authority to the ATP system
- Train detection systems which detect the location of trains
- Movable bridges

3.1.5 Train Control

The train control initiates the control input such as traction and braking commands. The commands are based on the timetable, the currently applicable movement authority, and the static speed profile. These commands are sent to the braking and traction systems.

3.1.6 Automatic Train Protection

Automatic Train Protection (ATP) is a safety critical system which enforces the movement authority. Different types of ATP systems exist, differing in functionality, the provided safety level and data exchange type.

The functioning of an ATP system can vary from only providing a warning whenever a warning (yellow) or danger (red) signal aspect is shown. To systems which only check if the brakes are applied when passing a warning (yellow) signal aspect. With the highest safety level provided by systems that offer braking curve supervision. These systems take into account the braking capabilities of the specific train and check at any point if the speed is sufficiently low to stop before the end of a movement authority i.e. a signal at danger.

Systems providing braking curve supervision The movement authority is the maximum distance a train can go. Furthermore, it includes a static speed profile indicating the maximum allowed track speed at every point along the route.

- **Static Speed Profile (SSP)**
  The static speed profile indicates the maximum allowed speed along a track, which depends on curves, and switches. Different static speed profiles can exist for different types of trains. For example, tilting trains can pass curves at a higher speed thus a different static speed profile applies in comparison to non-tilting trains.
- **Dynamic Speed Profile (DSP)**
  The dynamic speed profile does include the specific braking curve of a specific train, taking into account the movement authority and the static speed profile. Thus, the dynamic speed profile indicates the maximum speed a train can actually run at a given point.

Figure 6 below presents visually the concept of a movement authority indicated by a grey line, the static speed profile indicated in orange, and the dynamic speed indicated in red.

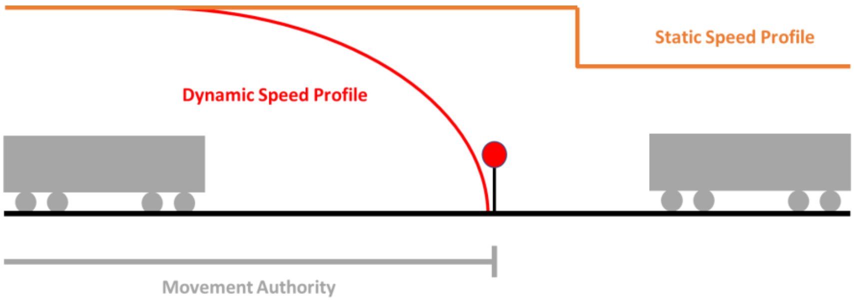


Figure 6 Movement authority indicated by grey bar, static speed profile (orange), dynamic speed profile (red)

The data exchange between trackside and onboard side varies with the functionality provided and the way of communication from intermittent systems to continuous systems.

Intermittent systems only exchange information at discrete points along the track, often using beacons which send the data. However, due to the intermittent nature drivers cannot immediately react to improvements in signal aspects. A new movement authority corresponding to the improved signal aspect can only be obtained at a beacon. A release speed is implemented to enable train drivers to drive towards the beacon which is at the end of the movement authority.

Continuous systems do not have this problem. Continuous systems information continuously either by continuous cable loops in the track, coded track circuits or radio communication. Continuous data exchange allows the movement authority to be updated whenever a new movement authority is available.

3.2 Automatic Train Operation

The degree to which fundamental tasks are automated is defined according to the Grade of Automation (GoA). The grades of automation are defined in IEC standard 62290 (UITP, 2012).

Figure 7 presents an overview of the Grades of Automation defined in the IEC standard. The majority of railways operates in GoA 1. A train driver operates all fundamental tasks, however, an automatic train protection system supervises the movements. GoA 2 systems automate the basic driving function of setting the train in motion and stopping the train, however, door closure and disruptions are a task of the train driver. GoA 3 does not require a driver to be present in the front of the train. Door closure and operation in event of disruptions are still the task of a person, but, this person can freely roam the train under normal operation. GoA 3 requires either a closed system which minimizes the chance of obstacles on the track or automatic obstacle detection. GoA 4 removes the need of a person to be present on the train all together, all functions defined in figure 7 are automated.

Grade of Automation	Type of train operation	Setting train in motion	Stopping train	Door closure	Operation in event of Disruption
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 2	ATP and ATO with driver	Automatic	Automatic	Driver	Driver
GoA 3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA 4	UTO	Automatic	Automatic	Automatic	Automatic

ATP - Automatic Train Protection   ATO - Automatic Train Operation

Figure 7 Grades of Automation (UITP, 2012)

An ATO GoA 2 system is not a safety critical system. Safety is guaranteed by the ATP system which intervenes whenever the train exceeds its movement authority. The role of the driver changes to a supervisor role. He/she is responsible for starting the ATO and can take back control at any moment. Furthermore, door control and operation in event of disruptions remain tasks of the train guard/driver as well.

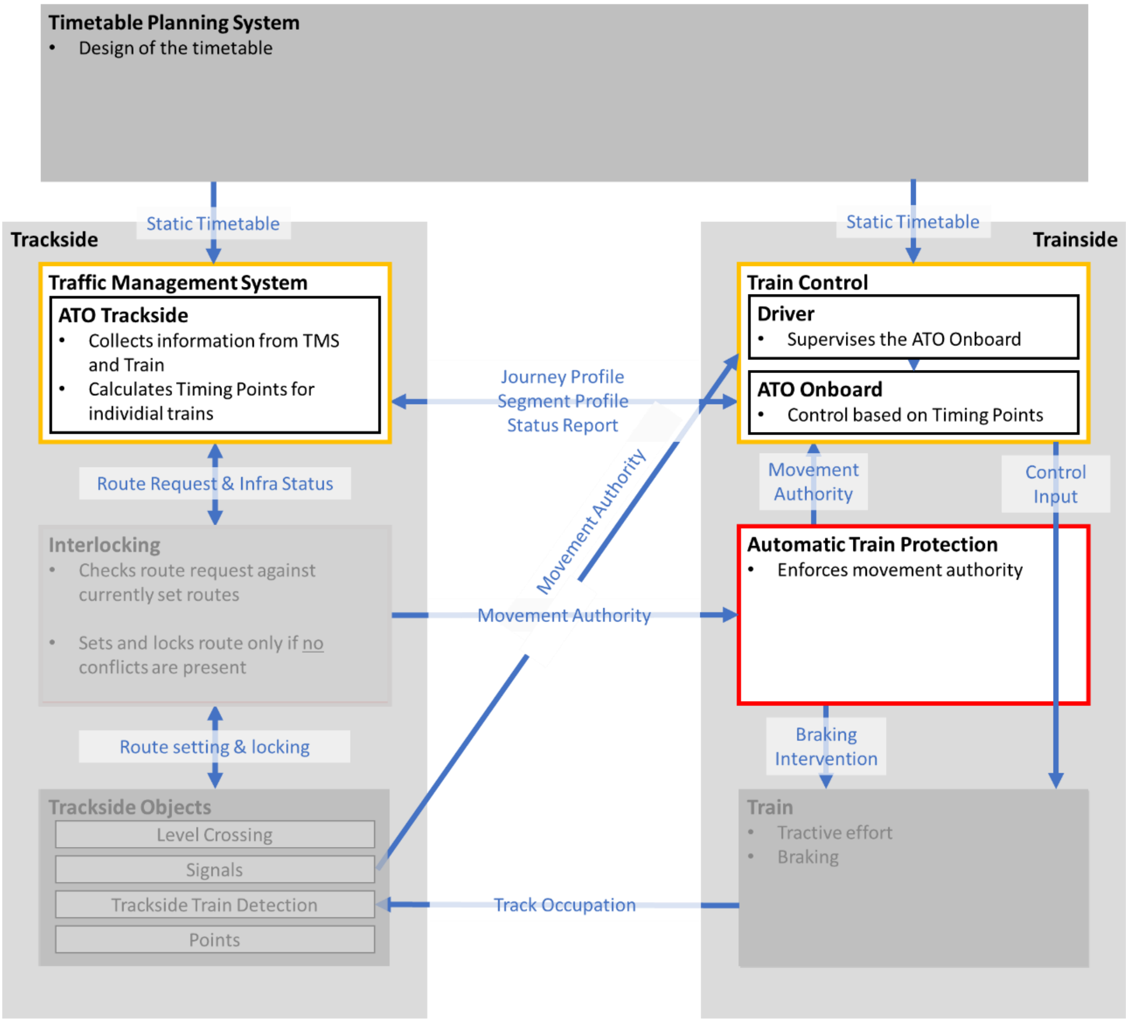


Figure 8 Generic system architecture Automatic Train Operation Grade of Automation 2.

Figure 8 shows a generic system architecture of ATO GoA 2. ATO requires two additional systems, an ATO onboard and an ATO trackside. The ATO trackside is added to the Traffic Management System Its task is composing the most up to date timetable (journey profile), providing an up to date description of the infrastructure (segment profile), and relaying the status report received from the ATO onboard system back to the TMS system. The interface between the ATO-trackside and ATO-onboard system is used to exchange two sets of information. (i) the journey profile and (ii) the segment profile. The ATP system provides the safety envelope. The ATO onboard produces the control input based on the journey profile, segment profile, and safety envelope.

The journey profile model is an important concept for ATO on mainline railways. It is developed for ATO over ETCS (Lima-Vanzeler, 2018) and used for the SFERA interface as well. This model describes on a high level what data is required for ATO. The data is grouped in two categories the Journey Profile (JP) and the Segment Profile (SP), The journey profile includes the timetable and the specific route. The segment profiles describe a specific track segment.

3.3 Automatic Train Operation over European Train Control System

The European Train Control System (ETCS) is the European standard for an interoperable signalling system and ATP system. It was developed to replace existing national signalling and ATP systems allowing for easier cross-border train traffic. ATO over ETCS is currently under development. A brief description of the ETCS system itself is given in section 3.3.1. ATO over ETCS is discussed in 3.3.2.

3.3.1 Brief Description of the European Train Control System

ETCS can be implemented according to different levels, which each have different characteristics. All levels of ETCS provide continuous braking curve supervision and in-cab signalling.

- **ETCS Level 1**

  ETCS level 1 is an intermittent ATP system. The movement authority is sent to the train at discrete locations using eurobalises (standardized beacons), indicated in yellow in figure 9. The option exits to implement infill loops. Infill loops allow a new movement authority to be sent to the train over a longer distance.

  Trackside train detection systems determine if a block is occupied or not. Trackside train detection is indicated by the red line in figure 9.

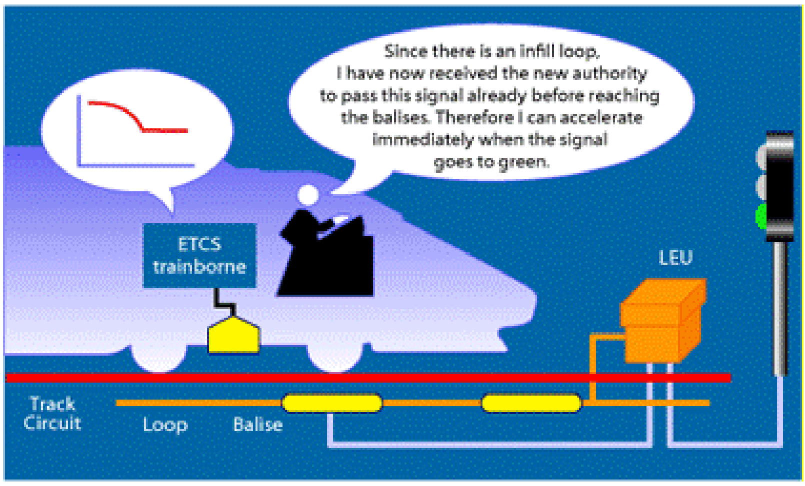


Figure 9 ETCS level 1 (UNIFE, 2019)

- **ETCS Level 2**

  ETCS level 2 is a continuous ATP system. The movement authority is sent to the train by the radio block center using radio communication over GSM-R, indicated in by the yellow dotted line in figure 10. The movement authority is always up to date because of the continuous radio communication. Therefore, no trackside signals are necessary, the train driver receives all information via the ETCS Driver Machine Interface.

  Eurobalises are used to calibrate the odometry systems of the train, because the location of the eurobalise is known precisely. The passage of a eurobalises resets the error of the distance calculations.

  Similar as with ETCS level 1 trackside train detection determines if a block is occupied or not.

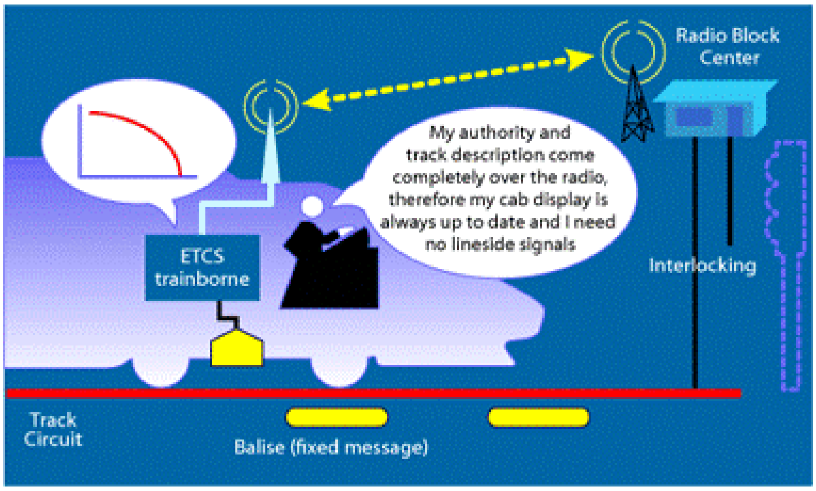


Figure 10 ETCS level 2 (UNIFE, 2019).

- **ETCS Level 3**
  ETCS level 3 is, similar to ETCS level 2, a continuous ATP system, with the movement authority being sent using GSM-R. The difference between ERTMS level 2 and 3 is in train detection. ETCS level 2 uses conventional trackside train detection. ETCS level 3 does not use trackside train detection systems.

  Trains running under ETCS level 3 report themselves their position to the radio block center. A train integrity module (TIM) ensures that the train is still in one piece. The radio block center can determine block occupation based on the location report of the ETCS onboard system.

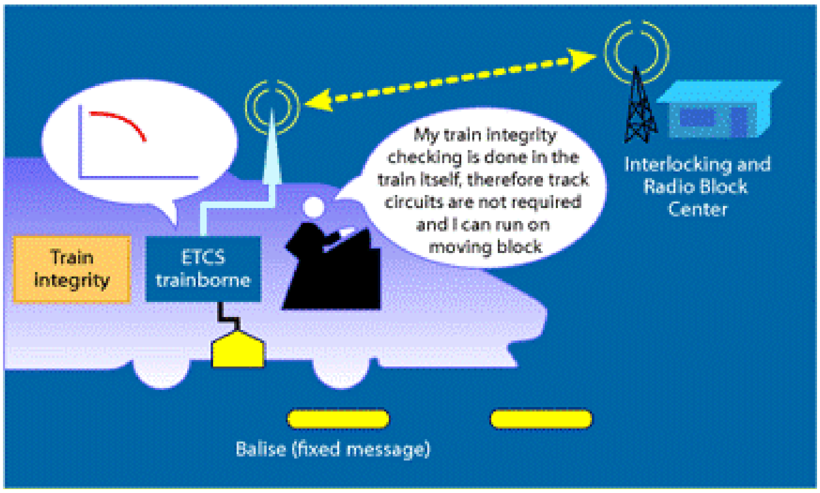


Figure 11 ETCS level 3 (UNIFE, 2019)

3.3.2 System Architecture ATO over ETCS

The specifications of ATO over ETCS is still under development. However, as stated in the literature review, much of the specifications is already written down in the mentioned subsets. The most relevant document for this research is Subset-125 (UNISIG, 2018a) because it discusses the system requirements for ATO over ETCS, the system architecture and the standard interfaces.

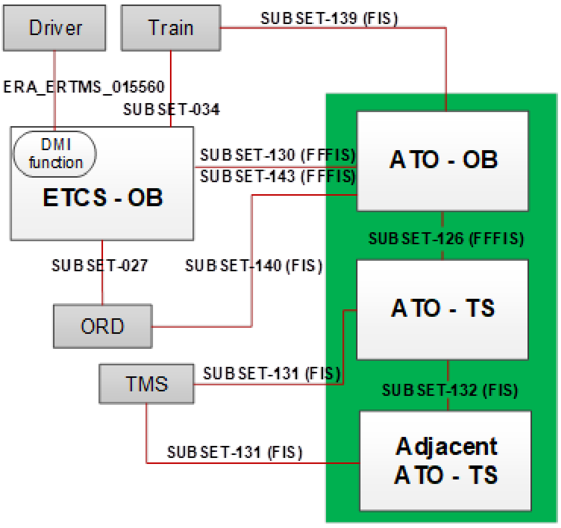


Figure 12 ATO over ETCS reference architecture, Grade of Automation 2 (UNISIG, 2018a)

Figure 12 and figure 13 show the developed system architecture and standard interfaces for ATO over ETCS. The figures are only valid for ATO Grade of Automation 2 and not valid for GoA 3-4.The basic principles mentioned for the generic system architecture still hold: ATO is not a safety critical system. An ATO trackside and ATO onboard are added to the railway control system. And status information, journey and segment profile are exchanged across the interface.

The specifics of the ATO over ETCS interfaces shown in figure 12 are described in various subsets. However, not all subsets are completed yet. This research takes into account subset-126, -130, and -139,(UNISIG, 2018b,c,d,) other subsets could not be obtained for this research. This chapter describes the details of the interfaces.

System Architecture with ATO over ERTMS, GoA 2

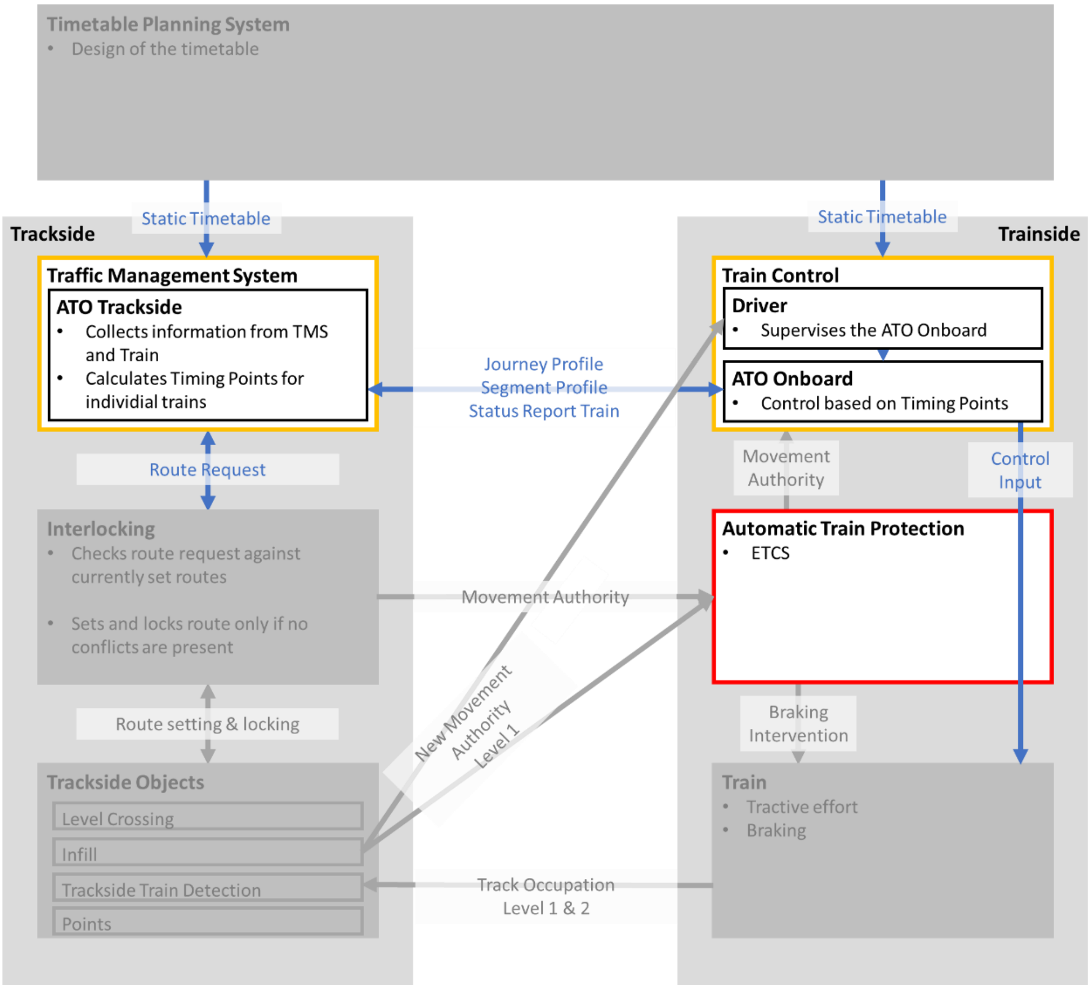


Figure 13 System architecture ATO over ERTMS, Grade of Automation 2.

Interface ATO-Trackside – ATO-Onboard

Subset-126 defines the interface between the ATO-Trackside and ATO-Onboard. Journey profiles, segment profiles, and the status reports are exchanged between the ATO-Trackside and ATO-Onboard. The in subset-126 (UNISIG, 2018b) defined variables have been further categorized, the allocation of variables is presented in Appendix B .

The Journey Profile (JP) is a description of the timetable of the train. The following groups of data are included:

- **Segment profile list**
  The segment profile list describes the specific route the train will take. The route is described by a list of successive segments the train will traverse.
- **Timing point list**
  The timing point list makes up the train path envelope. The location of the timing point is pre-specified within the segment profile. The journey profile data sent to the train completes the timing points with timing information: an arrival time and an arrival window tolerance, furthermore, for stopping points a departure time and a minimum dwell time are defined as well.
  Subset-126 prescribes certain choices about when to apply a timing point/window. Stopping points are always defined as timing points.
- **Temporary constraints**
  Temporary constraints such as a speed restriction, low adhesion area, or ATO/DAS inhibition zone are part of the journey profile as well.

The segment profile itself, is a comprehensive description of the infrastructure. The infrastructure is described by cutting up the infrastructure into different segments. Each segment profile is made up of static infrastructure data. Therefore, a set of segment profiles describing an area of infrastructure may be pre-loaded into the ATO onboard. The following data is included:

- **Segment profile characteristics**
  The segment profile is identified by its identification number and its length. The identification number is unique on a country level.
- **Static speed profile, gradients, and curves**
  The static speed profile is equal to the static speed profile defined for the ETCS system. Thus, the parameters which define an ETCS static speed profile are used in the segment profile as well. The static speed profile, gradient profile, and curve profile are defined by respectively a starting speed, gradient, or curve and changes to the starting, speed, gradient, or curve.
- **Electrification system**
  Furthermore, the traction system and maximum allowed current consumption stated for each segment.
- **Balises**
  A list of ETCS balises which are present within the defined segments is sent to the ATO onboard.
- **Timing points**
  The static characteristics of the timing points are specified within the segment profile. This includes the identification number, location, stop tolerance, and a definition on when the stopping point is reached.
- **Additional infrastructure information**
  The following set of additional information is included in the segment profile. Platform areas, tunnel areas, powerless areas, and permitted brake system areas (switch off regenerative, eddy current, or magnetic shoe brake areas).

The ATO onboard has a comprehensive overview of the state of the train. This information is sent back to the ATO trackside. The status rapport of the train can include the following data:

- Current position and speed
- Estimation of arrival time on upcoming timing points

Interface ETCS-Onboard - ATO-Onboard

The interface between the ETCS-Onboard and the ATO-Onboard is laid down in subset-130 (UNISIG, 2018c). This subset describes four groups of data which are sent from the ETCS-Onboard to the ATO-Onboard: static train data, dynamic train data, supervision data, and positioning data. The specific allocation of variables is presented in 8.2Appendix C

Static Train data consist out of train characteristics and braking curve characteristics. Train characteristics data is used to identify the train. The operational and train identification number are used to ensure the correct data is received from the ATO trackside. Furthermore, the braking curve can be characterized by the data transmitted from the ETCS onboard. This data ensures the train knows its identity and capabilities.

- **Train characteristics**
  - Operational number (train number)
  - Train identification
  - Driver identification
- **Braking curve characteristics**
  - Applicable SSP: cant deficiency category, train category, and axle load category
  - Train characteristics: antenna location, maximum speed,
  - Braking characteristics: brake percentage, nominal rotational mass

Dynamic Train data consists of conditions. ATO can only be engaged when these conditions are fulfilled.

- **Conditions**
  - Chosen Direction
  - ETCS in full supervision mode
  - ETCS in Automatic Driving (AD) mode
  - Validity of ETCS Data

ATO itself is not a safety critical system. It is the automatic train protection system which provides the safety critical function of ensuring the train stays within its movement authority. Therefore, ATO can only be engaged if ETCS is in the automated driving mode (AD mode). AD mode is available when all train/track data is available and can only be activated by driver action (ERA, 2018). When in AD mode ETCS acts as in its normal Full Supervision mode, however the indication, permitted and warning supervision limits are not presented to the driver, figure 14 presents an overview. Furthermore, no Service Brake Intervention (SBI) is triggered when the SBI supervision limit is exceeded. These additional limits are used to indicate to the driver an action is needed and give time to act. ATO does not need these early indications, the result is ATO being capable of driving more closely to the Emergency Brake Intervention (EBI) curve.

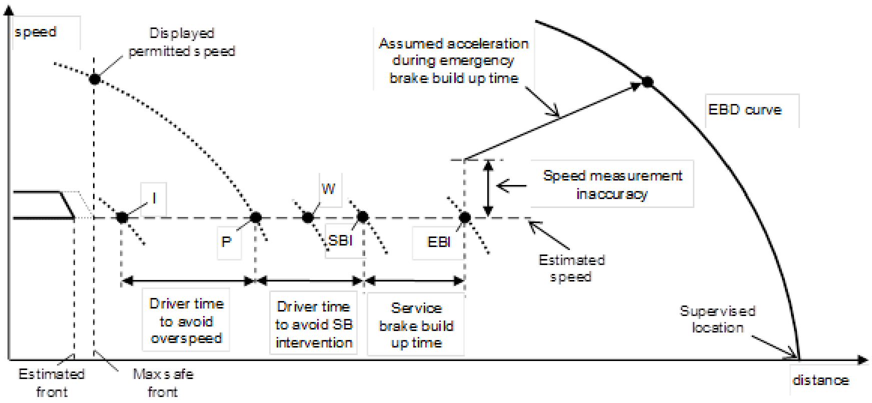


Figure 14 Overview of Emergency Brake Deceleration curve and the derived supervision limits (ERA, 2016)

Supervision Data consists out of all the data required to allow the ATO onboard to adhere to the movement authority. The supervision data contains information about the current movement authority. This includes the applicable speed profile (which can be defined beyond the movement authority), the location at which the movement authority ends, the permitted speed at the current location, and the release speed which is applicable at the end of the movement authority. Furthermore, information about track characteristics which are relevant for the braking performance of the train are included in this data. This consists out of the gradient profile and the adhesion profile:

- **Movement Authority**
  - End of authority location
  - Applicable release speed
- **Static Speed Profile**
  - Permitted speed at current location
- **Gradients**
- **Adhesion**

ETCS determines the position of the train based on odometry data from the train and balises present in the track bed. The information the ETCS onboard sends to the ATO onboard allows the train to determine its position, ensuring ETCS and ATO use the same train position.

- **Position**
- **Balise linking**
- **Current speed**

It must be noted that the accuracy of the positioning within ETCS. ETCS has a minimal accuracy of ± 5m or 5% of the distance since the last passed balise (RSSB, 2010). Even though a large advantage of ATO could be is its stopping accuracy, up to ± 0.5 m in current mainline application (RailEngineer, 2017). Thus, to support the high stopping accuracy of ATO requires a higher positioning accuracy of ETCS. One solution is to add additional balises, placed with a higher accuracy to increase the positioning accuracy of ETCS (NetworkRail, 2017).

Interface Train Control Management System - ATO-Onboard
Subset-139 (UNISIG, 2018d) specifies the interface between the ATO onboard and the train control management system, it must be noted that this subset is still under development. The following set of information is exchanged between the ATO onboard and the train (the allocation of variables is presented in 8.2Appendix D :

- **Traction and brake control**
- **Odometry**
- **Door control**
- **Train characteristics**

Interface Onboard Recording Device - ATO-Onboard
The interface between the ATO onboard and the onboard recording device is not yet specified. The function of the onboard recording device is to keep a record of all events and actions in the train for judicial reasons.

3.4 ATO over Class-B using SFERA Interface
The literature review already mentioned the similarities of the information exchange of DAS to ATO and the different categories of DAS. Therefore, solutions proposed for the implementation of DAS could also be used as a foundation for the implementation of ATO.

The implementation of Connected Driver Advisory Systems (C-DAS) is currently discussed at many infrastructure managers (Mitchell, 2018). However, implementations differ from infrastructure manager to infrastructure manager. Therefore, a standard interface for DAS and possibly ATO is proposed, the Smart communications For Efficient Rail Activities (SFERA) standard (Lima-Vanzeler, 2018).

3.4.1 SFERA underlying System Architectures
Figure 15 presents the system architecture of a C-DAS system. The relevant components for C-DAS have been highlighted, other components are greyed out.

The C-DAS Onboard has deliberately been placed in between the Trackside and the Trainside. The reasoning is that a C-DAS Onboard can just be a tablet the train driver takes with him/her and places in the train. A C-DAS does not have a connection with train systems such as ATP or Train.

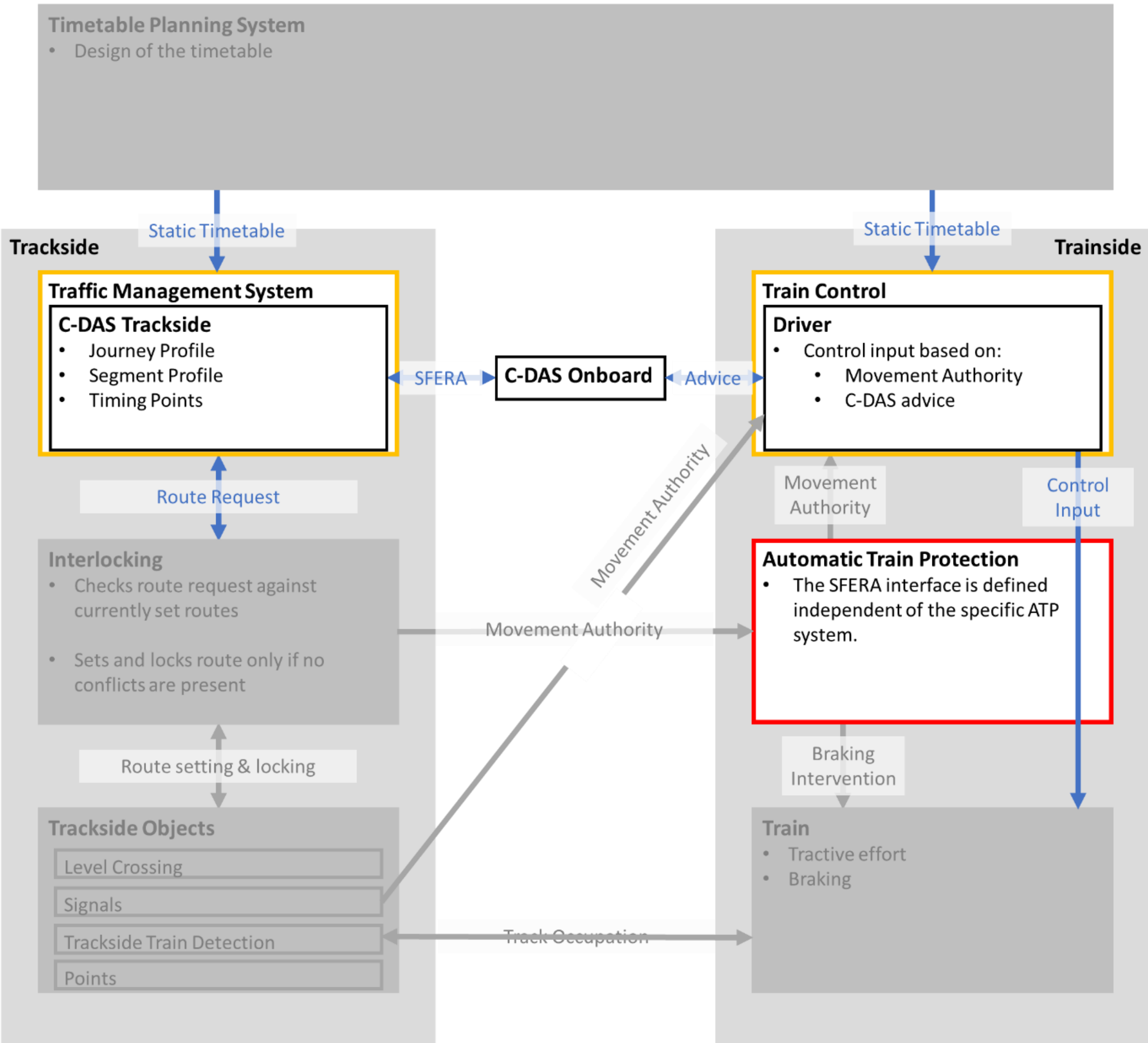


Figure 15 C-DAS system architecture.

Spiegel et al. (2018) define three system architectures to be supported by the SFERA standard. These are essentially three different options for the implementation of the C-DAS Trackside mentioned in figure 15. The first option (left in figure 16) is to implement two trackside systems, a system of the infrastructure manager and one of the railway undertaking. The SFERA interface is implemented between the systems. The second option (center in figure 16) is the implementation of an ATO trackside, according to the ATO over ETCS system. The ATO trackside must be provided with information form the infrastructure manager (journey profile, segment profile). It is proposed to provide this information according to the standardized SFERA interface (Lima-Vanzeler, 2018).Thirdly, a DAS trackside from the infrastructure manager can directly communicate to the DAS-Onboard system (right in figure 16). This option places the standard SFERA interface between the trackside and the onboard.

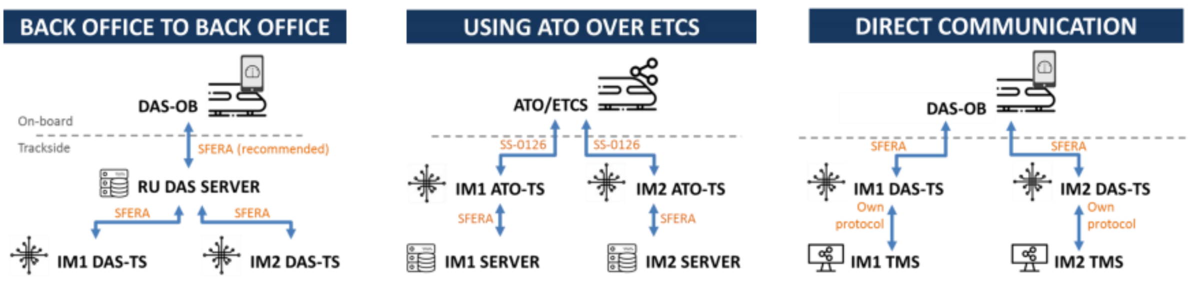


Figure 16 System architectures supported by the proposed SFERA standard interface (Spiegel et al,. 2018)

Furthermore, the literature review revealed three different implementations of connected DAS, based on the which system performs what part of the chain of computations. These systems are Centralized C-DAS, Intermediate C-DAS, and Onboard C-DAS (respectively DAS-C, DAS-I and DAS-O in figure 16).

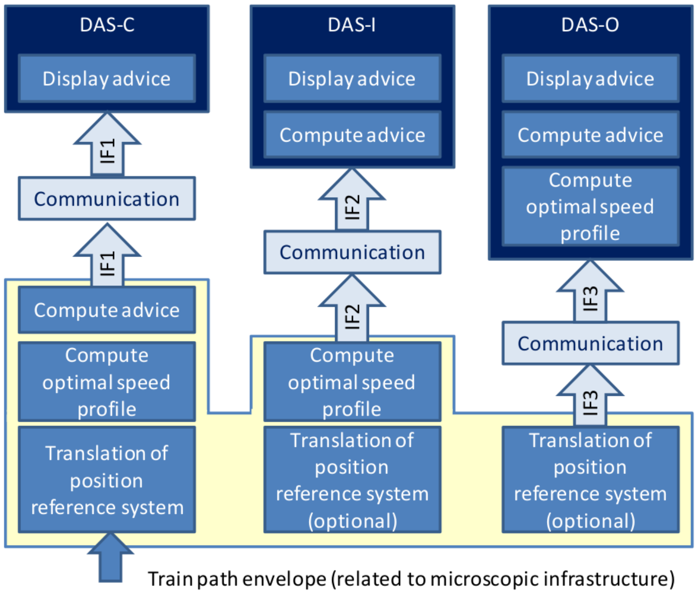


Figure 17 C-DAS system architectures (Lima-Vanzeler, 2018).

The different implementations of connected DAS each require a different information stream.

- DAS-C which centralizes the computations on the trackside requires information about the timetable (train path envelope), train and route characteristics, and current status information to calculate the optimal trajectory and an up to date advice.
- DAS-I does not require the traffic management system to know the current status information of the train[3]. The traffic management system calculates an optimal speed profile based on the train path envelope. The train itself calculates an advice based on the optimal speed profile and the current status.
- DAS-O centralizes the computations on the trainside.

The SFERA interface assumes a C-DAS-O approach in which the TMS system calculates a train path envelope and the trajectory and advice is calculated by an onboard system.

[3] Only for the DAS functionality, other functions of the TMS system, such as automatic route setting, can still require a set of current status information to be known.

3.4.2 SFERA standard interface

The SFERA standard is developed such that the information required for ATO over ETCS can be provided by SFERA (see figure 16). Given the similar information requirements the same information model is used for DAS applications. However, one set of information is added, the train characteristics. This is a result of a key difference between ATO and C-DAS, a C-DAS is not necessarily connected to the train. Thus, train characteristics cannot necessarily be obtained from onboard systems.

The following information is included in the SFERA interface specification. In figure 18 these are indicated between the C-DAS trackside and C-DAS onboard, but as stated before it could also be implemented between the infrastructure manager trackside and railway undertaking trackside and between the infrastructure manager systems and an ATO trackside.

- **Journey Profile (JP)**
- **Segment Profile (SP)**
- **Train Characteristics (TC)**

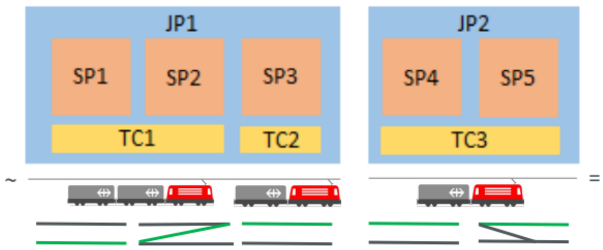


Figure 18 Visual representation of journey profile (Jonkers et al., 2018)

The different categories of information combine into a comprehensive description of the train journey (JP), the track configuration (SP) and the train characteristics (TC).

Segment profiles and train characteristics are fixed sets of information. If the during a journey the route changes a new journey profile with a new set of segment profiles must be sent to the train. Likewise, if train characteristics change because of trains being coupled, change in wagon load, or isolated brakes the journey profile must be updated.

3.5 The ProRail Traffic Management System

Traffic management starts with the daily timetable, which is produced by the Donna planning system. The Verkeersleiding Ondersteunend Systeem (VOS) system provides tool for the traffic managers. The procesleiding system is used by the dispatcher to make interventions into railway operations (Schaafsma, 2018).

The ProRail Traffic Management System (TMS) is a complex system made up of different components performing different functions. The core of the ProRail TMS system is made up of three components called the “Procesdriehoek”, these components are:

- **VOS**
  VOS is used by dispatchers to manage large disruptions of rail operations.
- **Procesleiding**
  A main component of the ProRail TMS system is Procesleiding. This system is used by signal operators to receive information of the infrastructure state, rail traffic state, and to set routes.
  Automatische Rijweg Instelling (ARI) is an automatic route setting system which is integrated in Procesleiding. It automatically sets routes based on a preprogrammed plan and trains passing trigger points.

- **ASTRIS**
  Aansturing en statusmelding van de railinfrstructuur (ASTRIS) receives the route requests from Procesleiding and sends it to the interlocking. Furthermore, Information about the status of the infrastructure is received by ASTRIS from the interlocking. Track occupation information is sent to TROTS and status of infrastructure elements is sent to Procesleiding.
- **TROTS**
  Trein Observatie en Tracking Systeem (TROTS) uses track occupation information to track trains across the network. Operational numbers (Train Numbers) are automatically allocated to trains. This information is sent to Procesleiding and VOS.

Figure 19 presents a high-level overview of the components of the ProRail Traffic Management System.

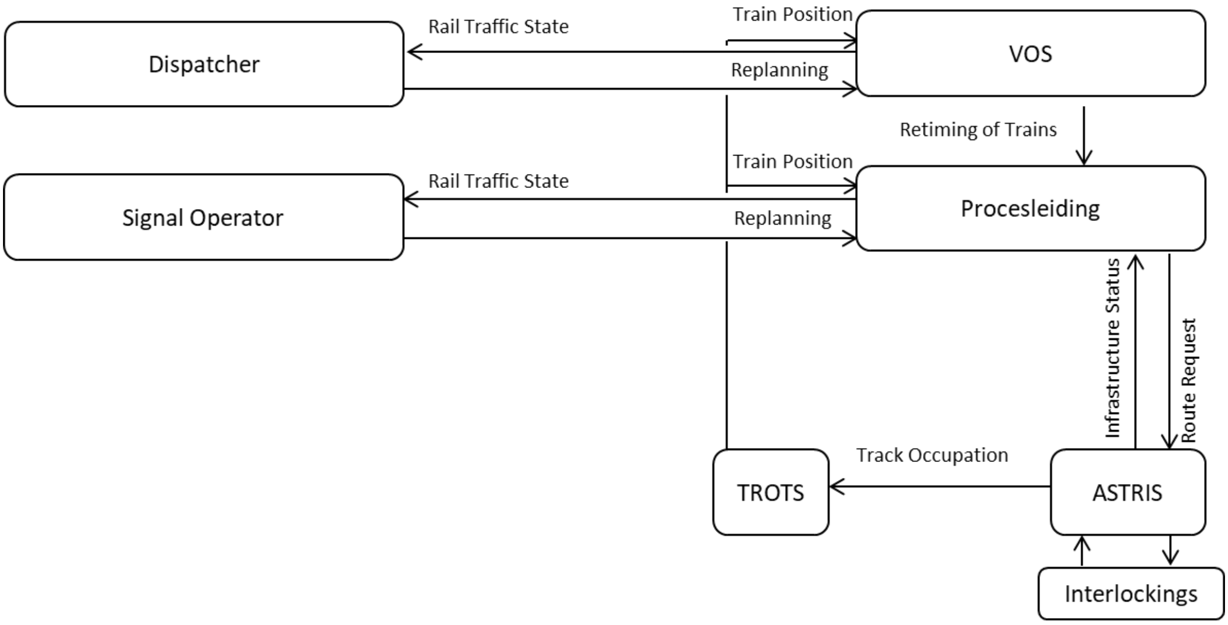


Figure 19 High level overview ProRail traffic management system.

Routelint presents additional information to the train driver about the state of the rail infrastructure ahead (Luipen, 2018). This includes track occupation and route reservations of other trains. The sources of this information might also be usable for ATO over ATB-NG.

Some dynamic traffic management is currently in place at the ProRail rail traffic management. The most notable example is the dynamic allocation of platforms at Schiphol Airport station.

4. Generic ATO model

The generic Automatic Train Operation model is a conceptual model. The goal of this conceptual model is to present an overview of the functions ATO provides, the required inputs, and the provided outputs.

This chapter presents the conceptual model. First, the function of the ATO system is presented. Secondly, functions require a set of inputs described next. Thirdly, an ATO system provides outputs which are described last.

The following starting points are taken into account in the development of the generic ATO model:

1. **ATO is a subsystem within the railway control system**
   For this generic model the ATO onboard and ATO trackside are taken as one ATO system.
   Assumptions are made about the presence of surrounding systems. These assumptions do not go into detail about the functions but rather concern a general high-level function.
    1. *Traffic Management System (TMS)*
       Provides a timetable to the ATO system.
    2. *Automatic Train Protection System (ATP)*
       Provides a safety envelope to the ATO system and enforces this safety envelope.
    3. *Train Control Management System (TCMS)*
       Executes the traction and braking commands given by ATO and contains a description of train characteristics.

2. **High level functional overview**
   The model describes functions, input information, and output information of the ATO system. The model describes the information required to fulfil the set of functions, irrespective of the specific surrounding traffic management, automatic train protection or train system. Thus it is assumed these systems are present but no specific type is taken in mind (example: ATP is assumed present but not specifically ETCS or ATBNG.

3. **Grade of Automation 2**
   The model is developed for Grade of Automation 2 system. Thus, the driver is ultimately responsible for the safe operation of the train.

4.1 Functions

Goverde and Theunissen (2018) define three functions for the ATO system to be performed. The task of an ATO system is to automatically run the train according to a trajectory.

1. The trajectory is generated based on the safety envelope, the timetable, route characteristics, and train characteristics.
2. The trajectory is tracked using the current status of the train to determine the required acceleration or deceleration to closely follow the trajectory.
3. Based on the required acceleration and deceleration traction and braking commands can be calculated.

Figure 20 below presents an overview of the function and tasks of an ATO system, more specifically the ATO onboard.

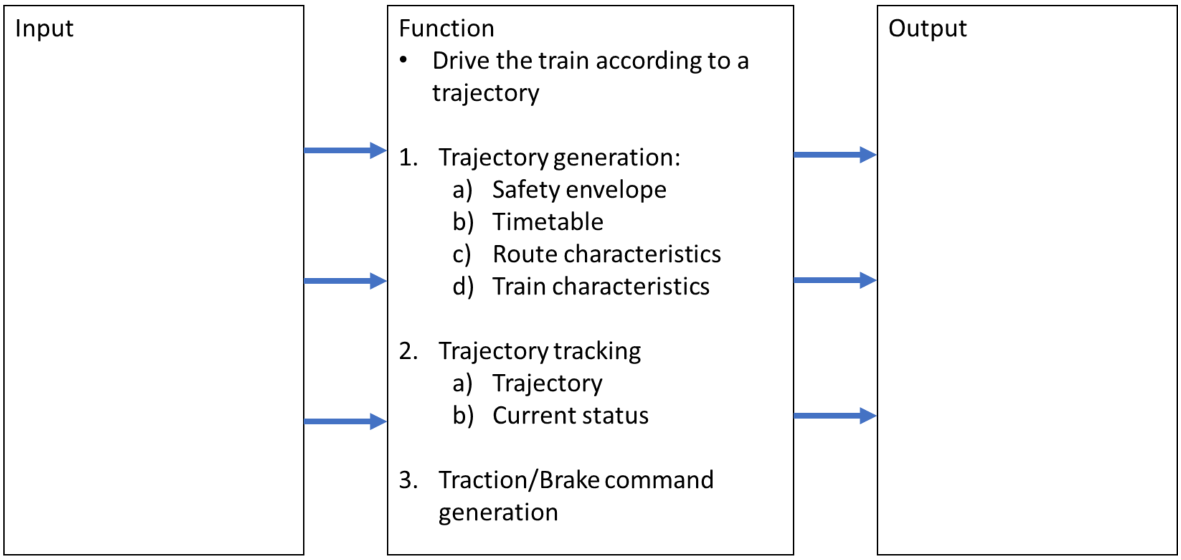


Figure 20 Conceptual model ATO, Function and tasks.

4.2 Input Information

The functions performed by the ATO system require input information. Section 4.1 defined five groups of information which must be known.

a) Safety envelope
b) Timetable
c) Route characteristics
d) Train characteristics
e) Current status

4.2.1 Safety Envelope

A train must, at all times, remain within the safety envelope. A train can travel at most to blocks which are free and reserved for the specific train. Although the ATO system is tasked with adhering to the safety envelop it is the ATP system which is tasked with the safety critical task to enforce the safety envelope.

Van den Top (2010) defines multiple envelopes within the envelope of safe operations model. Operational envelopes contain all states deemed acceptable by relevant organisations. Therefore, the relevant safety envelope is the operational envelope defined by the signalling and automatic train protection system.

The operational envelope defined by the signalling system depends on the following information:

- **Movement Authority**
  The maximum distance the train is authorized to travel.
- **Static Speed Profile**
  The maximum speed at any point along the route. Including temporary speed restrictions.
- **Starting conditions**
  A confirmation must be given to the ATO system ensuring the starting conditions are met. A GoA 2 system is not tasked with determining if the starting conditions are met. This is the task of the driver. Starting conditions include, doors safely closed, movement authority present.

4.2.2 Timetable

Furthermore, a train must adhere to its timetable. The journey profile is a description of the timetable of a train (Albrecht et al., 2013). It includes a series of timing points. A timing point consists of a location, target point/window, target speed, and stopping information.

The location of a timing point is static: a specific timing point has a fixed location.

The target point/window is dynamic and set according to the latest timetable of a specific train. A choice can be made between a target point or target window. Target points specify a single point in time at which a train has to arrive at/pass a location. Target windows provide a window in time at which a train can arrive at/pass a location. Target points are used for timing points published to travellers (example: stations stops), as a small deviation can be perceived as a delay by travellers (Wang & Goverde, 2016). Non published timing point (example: passing times at junctions) can be specified using target windows.

Target speeds are only necessary at critical locations such as minimum speeds before tunnels or slopes (Wang & Goverde, 2016).

It must be indicated to the train when a timing point contains a stop. This is included in the stopping information. Furthermore, the exact stop location can depend of the length of a train, this information must be sent to the train as well.

The previously discussed safety envelop always takes priority over the timetable.

4.2.3 Route Characteristics & Train Characteristics

An ATO system must operate the traction and brakes of the train. The tractive effort and braking effort must be calculated in such a way that the optimal trajectory is achieved. To accurately model the driving behaviour of the train both route characteristics and train characteristics are required (Albrecht et al., 2013). Route characteristics are defined in segment profiles.

Furthermore, precise information about stopping points is required. The exact location of stopping is dependent on the specific station track and the train length.

Therefore, a set of information describing route and train characteristics is required as input for ATO. The following information is included in this set:

- **Route Characteristics**
  - Segment Profile
    - Gradient profile
    - Adhesion profile
    - Curve profile
    - Traction system
    - Stopping points
- **Train Characteristics**
  - Traction Characteristics
  - Braking Characteristics
  - Resistance Characteristics
  - Train length

4.2.4 Current Train Status

Lastly an ATO system must be aware of the current status of the train. This includes the current speed, position, and traction/brake position of the train.

An overview of the ATO system is presented in figure 21. A summary of the input is now presented.

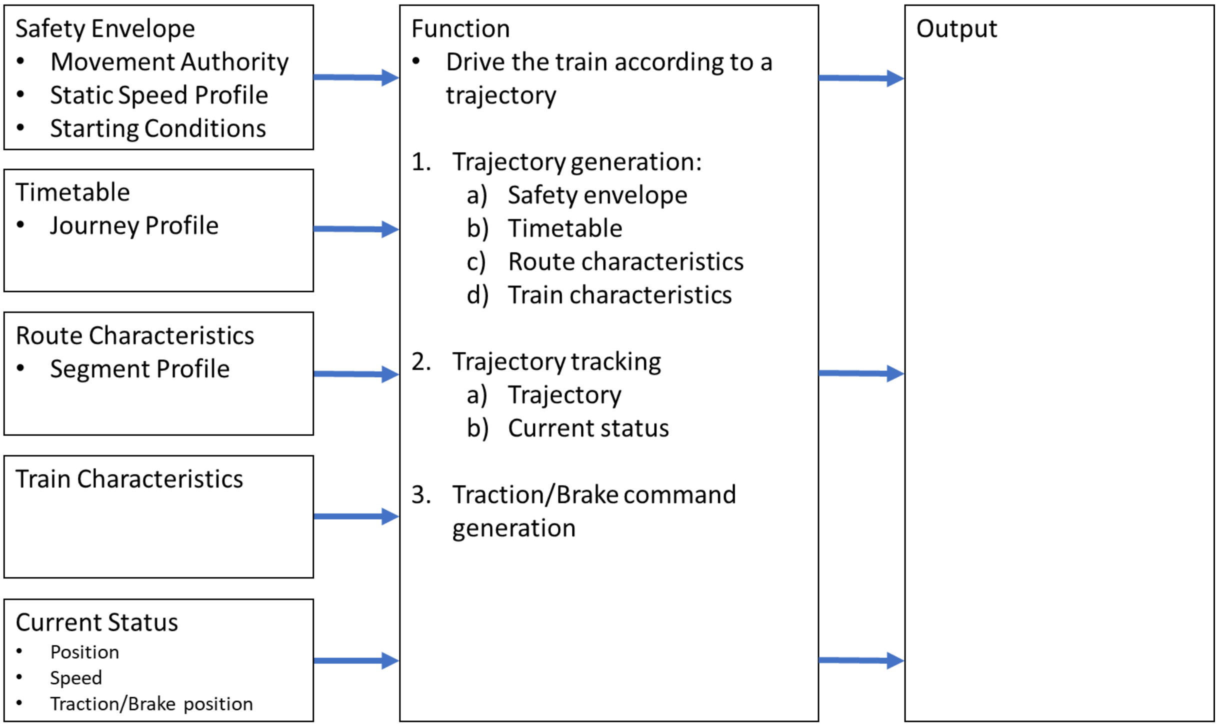


Figure 21 Conceptual model ATO, Inputs.

4.3 Output Information

After the ATO onboard system has executed its function a set of information is produced. The foremost output is the control command, which includes the tractive and braking effort.

Furthermore, both the current status of the train and the predicted arrival time of upcoming timing points (Timing point prediction) are outputs of the ATO system. The timing point prediction is relayed to the traffic management system.

The following set of information is included in the current and timing point prediction

- **Current Status**
  - Current speed
  - Current position
  - Operational status: The action ATO is currently taking: accelerating, cruising, coasting or braking.
- **Timing point prediction**
  - Time
  - Location
  - Operational status: Passing or stopping point
- **Control commands**
  - Braking command
  - Traction command

Figure 22 presents the overview of the ATO system completed with the output of the ATO system. Furthermore, the conceptual model is placed in the surrounding system landscape (an indication is give of what system in the rail control system should deliver an input and what system receives the output).

The generic ATO model presents an answer the following sub questions:

> *What functions are expected from the GoA 2 system/ Traffic Management System?*
> *What information is required for a GoA 2 system, both from track to train and vice versa?*

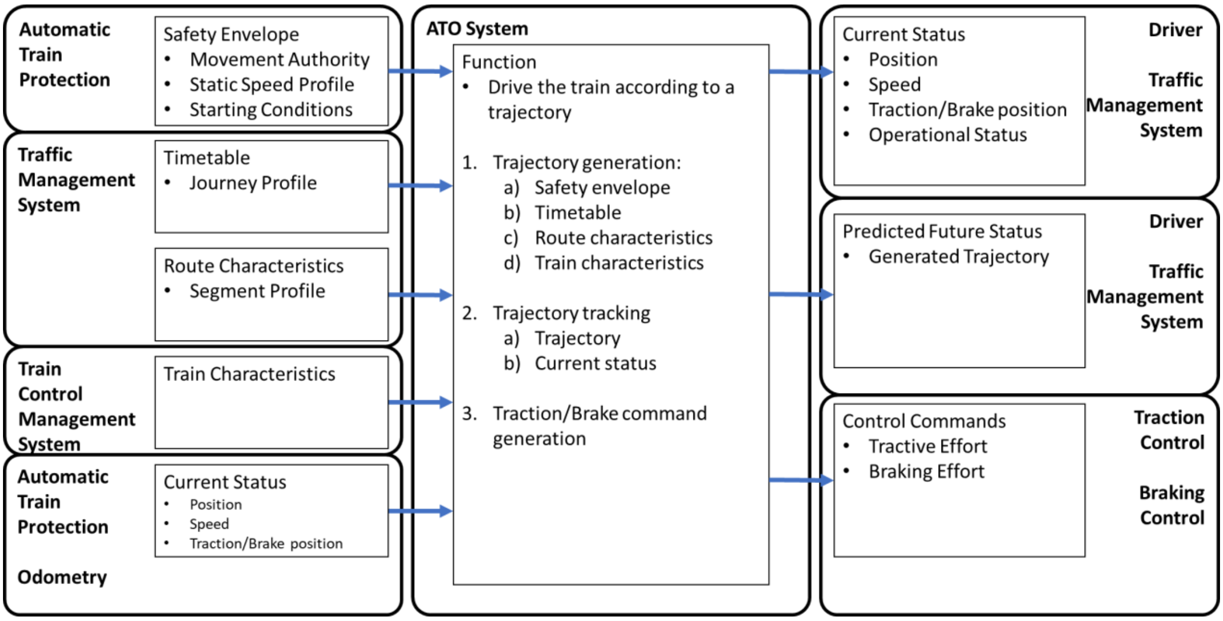


Figure 22 Conceptual model ATO.

5. ATO over ETCS

This chapter presents the ATO over ETCS system. The ATO over ETCS system is discussed according to the currently known specifications for ATO over ETCS. The chapter concludes with a SysML representation of ATO over ETCS.

5.1 Functional requirements of ATO over ETCS

This chapter presents a brief overview of the functional requirements specified for ATO over ETCS.

Currently, no specification exists of ATO over ATBNG. Previous research on the topic of ATO over ATB presented a set of guiding principles (Goverde & Theunissen, 2018). The guiding principles of ATO over ATB are based on the principles of ATO over ETCS (CER, 2016). The following list presents the guiding principles relevant for this research:

1. ATO developments must be compatible with the ETCS specification
2. ATO onboard and ATB onboard must be separate systems with a standard interface.

Guiding principle 1 presents a clear direction for the development of ATO over ATBNG. ATO over ETCS must adhere as much as possible to the ATO over ETCS specification.

The following list cites the functions defined for ATO over ETCS (ERTMS Users Group, 2017b). Only functions defined for GoA2 system are presented given the focus of this research. The functional requirements as defined for ATO over ETCS are presented in italics. Below each set of a small summary of the function is given.

An ATO GoA 2 system shall automatically drive a train from a stopping point to another stopping point

- *Following a command of the train driver*
- *If the train is not immobilized by emergency braking*
- *If the start of the train is not inhibited by the ATO trackside function*
- *If the train is not held for traffic regulation purposes (including for connecting services)*
- *If the dwell time has elapsed or departure time at the start of a journey is reached*
- *If the train is assigned a valid Journey Profile with valid Segment Profiles*
- *If train doors are confirmed closed and locked (if this information is available)*
- *Platform barrier systems are closed (if this information is available)*
- *Ignoring specific not safety relevant ETCS (ATP) curves*
- *Not using the emergency brake*
- *If the train has a valid movement authority*
- *ATO shall disengage whenever the train does not have a valid JP and SP for the route ahead*
- *Across a varied range of adhesion conditions based on information received from the ATO trackside.*

This first set of functional requirements for ATO over ETCS state that an ATO GoA 2 system shall drive a train from stopping point to stopping point. Thus, an ATO GoA 2 passenger train can automatically run from station to station taking into account both the timetable and the operational envelope of ETCS.

An ATO GoA 2 system shall react on braking and traction inputs by the driver

- *By disengaging upon a braking input*
- *By ignoring traction input and inform the driver by a warning*

The driver is responsible for the safe movement of a train under a GoA 2 system. Therefore, the system has to react on a braking intervention by the driver by braking and disengaging the ATO system.

An ATO GoA 2 system shall automatically stop at a predefined stopping point

- *Only if the status of a stopping point is received sufficiently early to reach the stopping point with a service brake application*
- *stopping the train to a positional accuracy that supports the operation of the platform/train interface or loading/unloading system*
- *Automatic driving shall be disengaged when the train has stopped at a Stopping Point*
- *An indication shall be provided to the train driver to indicate when the train has undershot, overshot or stopped within the Stopping Point tolerance*
- *At defined stopping locations, if the ATO train fails to reach the Stopping Point, the ATO onboard function shall automatically jog forward the train, maintaining the train doors closed and locked, until the train is correctly aligned*
- *At defined stopping locations, if the ATO train overruns the Stopping Point by a distance less than the acceptable limit (the rollback tolerance), the ATO on-board function shall automatically jog backward the train, maintaining the train doors closed and locked, until the train is correctly aligned*
- *An ATO GoA 2 will not automatically open the doors upon reaching the stopping point*

A grade of automation 2 system stops the train automatically at a station. The stopping accuracy is not prescribed but chosen for the specific situation. The ATO system is allowed to make adjustments within a confined area if the stopping location is not reached with sufficient accuracy. The achieved stopping performance (undershot, overshot, or stopped within tolerance) is indicated to the driver. Doors are not opened by the ATO system, the driver is responsible for unlocking the doors.

An ATO GoA 2 system shall remain engaged while passing a level crossing

- *A protected level crossing will be passed automatically*
- *For unprotected Level Crossings, it shall be possible to configure if the Level Crossing is to be crossed automatically or if ATO is braking the train towards the level crossing*
- *The driver shall acknowledge an unprotected level crossing in order to pass the level crossing in automatic driving. If the acknowledgement is not received the train shall stop in rear of the level crossing.*

Level crossings are passed automatically by the ATO system. The train driver is responsible for observing if the level crossing is free of obstacles. If the level crossing is not free the driver will intervene and the ATO system will disengage according to previously stated functionality.

An ATO GoA 2 system shall be able to operate several coupled units as a single train

- *An ATO GoA 2 system has the possibility to automatically join multiple units after a command from the train driver*
- *An ATO GoA 2 system has the possibility to automatically split multiple units after a command from the train driver*

The ATO system is capable of driving trains in multiple different configurations, with several units coupled together. Therefore, the ATO system shall be capable of determining the configuration of the train and be able to use different traction/braking characteristics depending on the train configuration.

An ATO GoA 2 system shall provide a DAS function when ATO GoA 2 is not engaged

If the ATO system is not engaged but journey profiles and segment profiles have been sent to the train DAS functionality is provided to the train driver.

5.2 Mapping ATO over ETCS on Generic ATO Model

The system architecture for the ATO over ETCS is known. The specifications of ATO over ETCS state how the information required by the ATO-Onboard is delivered and by what subsystem. Therefore, the input information and the output information can be mapped on the subsystems of ATO over ETCS.

5.2.1 Functions, ATO over ETCS

Subset-125 (UNISIG, 2018a) specifies the various functions of ATO over ETCS. The ATO driving function is defined by four functional features:

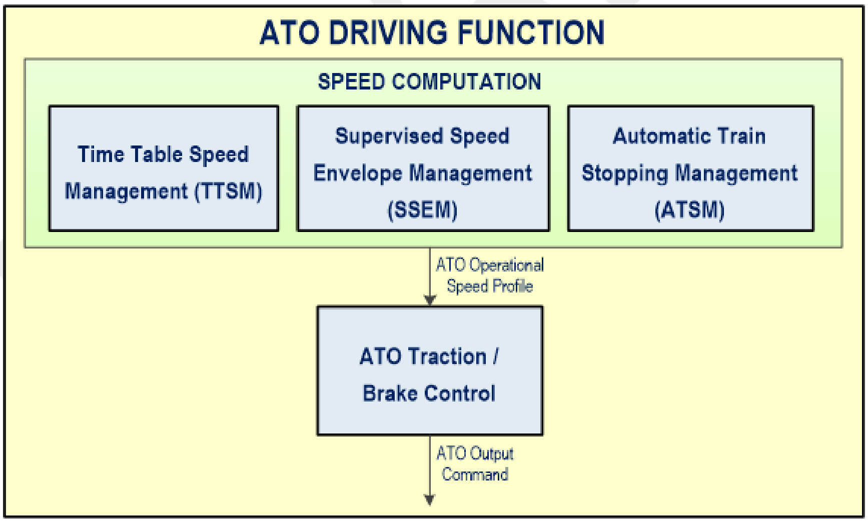


Figure 23 ATO driving function (UNISIG, 2018a)

The functions defined in subset-125 (UNISIG, 2018a) map straightforward onto the generic model defined in chapter 3. The following lists discusses how the functions are mapped.

- **Trajectory Generation**
  This function is separated into three different sub functions for ATO over ETCS. Adhering to the signalling operational envelope, timetable, and stopping at the right location are separated.
  a. **Safety envelope:**
     Supervised Speed Envelope Management (SSEM)
  b. **Timetable: running according to the timetable**
     Time Table Speed Management (TTSM)
  c. **Timetable: stopping at the right location**
     Automatic Train Stopping Management (ATSM)
- **Trajectory Tracking**
  Trajectory tracking is included in the TTSM function and the SSEM function
- **Traction/ Brake command generation**
  ATO Traction/ Brake Control

Within the freedom provided by the timing points of the journey profile ATO over ETCS optimizes for energy efficiency. Subset-125 (UNISIG, 2018a) states: *"Timetable Speed management: establishes the optimum speed to achieve the Stopping or Passing Points on* *time in the most energy efficient way."* Thus, for ATO over ETCS the freedom provided within the train path envelope is used to save energy.

5.2.2 Inputs ATO over ETCS

Subset-125 (UNISIG, 2018a) specifies the data exchange between the ATO-Onboard and various adjacent system such as the ATO-Trackside (subset-126). The following inputs are defined.

Input: Safety Envelope

The safety envelope is provided by the ETCS onboard system in the ATO over ETCS system architecture. The safety envelope of ATO over ETCS is made up of multiple different envelopes. These envelopes are discussed according to the envelope of safe operation model (Van den Top, 2010).

The envelope supervised by ETCS is an operational envelope. It is a set of rules which the train driver or ATO system must comply with. The ETCS braking curve is based on a guaranteed emergency brake deceleration. Railway Undertakings define a set of correction factors corresponding to a level of confidence in the braking curve. The infrastructure manager sets the level of confidence to be used. Applying the correction factor results in a Nominal brake deceleration (ERA, 2016). The result is a ETCS braking curve which fits within the controllability envelope. The correction factors provide a safety margin between the actual emergency brake rate and the assumed braking rate by ETCS.

The ETCS operational envelope is the safety envelope provided by the ETCS onboard system in the ATO over ETCS system architecture. ETCS is tasked with the safety critical function of computing and enforcing the movement authority using a dynamic speed profile. Whenever the ATO system operates the train such that the movement authority is passed, the ETCS will intervene with a brake intervention.

According to subset-125 (UNISIG, 2018a) the ATO system is tasked with predicting and complying with the dynamic speed profile (DSP) supervision curves of ETCS. Therefore, the ATO system receives the same information as the ETCS onboard to calculate the braking curves as does ETCS. The information includes:

- Train Characteristics
- Braking curve characteristics
- Conditions
- Movement authority
- Static speed profile
- Gradients
- Adhesion
- Position & balise & current speed

Input: Timetable

The timetable information for ATO over ETCS is defined in the journey profile. The information originates from the traffic management system. The ATO trackside system collects this information and converts the information to the data format described in subset-126 (UNISIG, 2018b).

One difference between the literature based generic model and the journey profile used for ATO over ETCS is the absence of a target speed in the journey profile. Thus, no target speed can be prescribed. This might be of concern with heavy freight trains and steep gradients or tight curves which mandate a minimal speed from an operational point of view.

Input: Route Characteristics

Route characteristics are defined in the segment profile for ATO over ETCS. Segment profiles are not yet available within the traffic management system. Information currently available in the Infra Configuration must be translated into the standard ATO over ETCS format. Furthermore, special attention must be given to defining Timing Points. Currently, Dutch timetables are defined at Dienstregelpunten, specific points at which a passing, arrival, or departure time is defined. A study of ProRail identifies that Timing Points not necessarily overlap with Dienstregelpunten, and further research is required to properly define Timing Points.

Input: Train Characteristics

The train characteristics provided under ATO over ETCS are used for two purposes. The first purpose is to allow ATO to calculate the applicable ETCS supervision curves. The second purpose is to feed ATO with the information necessary to calculate the tractive and braking effort required to achieve the optimal trajectory.

Train characteristics are provided by the ETCS-Onboard and by the Train Control Management System. The ETCS-Onboard delivers the braking characteristics required to calculate the braking curves. The Train Control Management System delivers braking and traction characteristics required to calculate an optimal trajectory within the ETCS operational envelope and adhering to the timetable.

Input: Current Status

The current status of the train is provided by a combination of information from ETCS and the train systems (traction/ braking). ETCS provides odometry information which allows the ATO onboard system to determine its position. The train provides the traction/braking status, furthermore, raw data from the odometry system is provided as well.

The current status is provided by the ETCS-Onboard and by the Train Control Management System. Both systems deliver current speed and odometry information.

5.2.3 Outputs ATO over ETCS

Subset-125 (UNISIG, 2018a) specifies the data exchange between the ATO-Onboard and various adjacent system such as the ATO-Trackside (subset-126). The following outputs are defined.

Output: Current Status

The current status of the train is sent to the ATO-Trackside. The ATO-Trackside will relay this information to the traffic management system.

The ETCS Driver Machine Interface (DMI) is used to present the current ATO status to the train driver.

Output: Timing point prediction

The ATO onboard predicts an estimated arrival time for at least the next timing points. Subset-126 (UNISIG, 2018b) allows for the transmission of predictions for multiple timing points.

The Timing Point prediction is sent to the ATO trackside, the ATO trackside will relay this information to the Traffic Management System.

Output: Traction/Brake Command Generation

The control commands are sent to the braking and traction systems of the train.

The traction and braking systems have to interpret inputs from multiple sources and determine which input takes priority. ATO over ETCS (subset-125 (UNISIG, 2018a)) sets the following priorities:

- **Braking**
  1. ETCS intervention
  2. Driver command
  3. ATO command
- **Traction**
  When ATO is engaged traction commands from the driver are ignored.

5.3 Overview of information exchange ATO over ETCS

Figure 24 presents the system architecture of ATO over ETCS using a SysML model. The figure contains the systems (boxes) and the data exchange between the systems (arrows).

The ProRail traffic management system is included in the figure. The connection to the ProRail traffic management system is not specified yet. However, certain assumptions can be made:

- The journey profile is a combination of information from Procesleiding and VOS.
  - Procesleiding delivers routes
  - VOS delivers the arrival or passing times at timing points
- The infra configuration is expanded with segment profiles, include timing points.

5.3.1 Main system components and interfaces

Two new system components are added to the railway control system. The ATO trackside and the ATO onboard. These system components interface with other systems in the railway control system. The main interfaces are:

- ATO Trackside – ProRail TMS
- ATO Trackside – ATO Onboard
- ATO Onboard – ETCS Onboard
- ATO Onboard – Other train systems

5.3.2 The ATO Trackside

The left side of figure 24 describes the trackside systems of the railway control system. ATO adds the ATO trackside system. This system collects the journey profiles and segment profiles from the ProRail traffic management system. The ATO trackside sends the collected journey profile and segment profile to the corresponding train.

The journey profile is dynamic and is therefore collected from both VOS and Procesleiding. VOS is used by dispatchers to re-plan trains in time, thus defining the target points/windows of timing points. Routes are set by signal operators using Procesleiding. Therefore, Procesleiding defines the consecutive segment profiles a train will traverse. Delays are processed by dispatchers in Procesleiding as well. Thus small changes in timing points may be made by Procesleiding as well.

Segment profiles are static and are therefore collected from the infra configuration database. Timing point locations are static as well. Even though timing point locations are technically part of the segment profile, because of their importance for ATO these are included as a separate information stream.

Besides collecting information from the ProRail traffic management system, information is collected form the ATO onboard as well. This information contains a current location, current speed, and a timing point prediction.

The timing point prediction contains an estimated arrival time at upcoming timing points. The ATO trackside sends this information to the ProRail traffic management system. Currently, Procesleiding and VOS are not capable of using the current location, current speed, and timing point prediction. Therefore, a new function must be added to both VOS and Procesleiding.

The function allows VOS and Procesleiding to present the information to the dispatcher and signal operator, allowing them to base decisions on a predicted future rail traffic state.

One solution could be an automatic real-time traffic management system. Different systems are proposed in literature. A commonality is the presence of multiple different modules which each perform a single task. These tasks include: traffic state prediction, conflict detection, and conflict resolution.

5.3.3 The ATO Onboard

The right side of figure 24 describes the onboard systems of the railway control system. ATO adds the ATO onboard system. The ATO onboard determines and sends traction/braking commands based on the journey and segment profiles, the ETCS operational envelope, and the train characteristics.

The ETCS onboard, located bottom right in figure 24, sends the train characteristics, braking curve characteristics, conditions, movement authority, gradient, adhesion, and positioning information to the ATO onboard. The train characteristics and braking curve characteristics are used by ATO to determine the relevant braking curves. The ATO onboard can only be engaged whenever the conditions (ETCS in correct mode, no intervention) have been fulfilled. The ETCS onboard sends qualifiers to the ATO onboard indicating whether the condition has been fulfilled. The ETCS onboard receives the operational envelope from the ETCS trackside either via GSM-R or eurobalises. The information includes a movement authority, a static speed profile, a gradient profile, and a adhesion profile.

ETCS determines the position of the train based on a known location of the eurobalises and odometry systems. The ATO onboard does not have direct access to the odometry systems. All positioning information is sent to ATO onboard via the ETCS onboard.

Traction and braking models are used by the ATO onboard to determine the correct control commands. The traction and braking models depend on the characteristics of the train. Furthermore, if the composition of the train changes (by coupling or uncoupling) or when brakes are isolated these characteristics change as well. Therefore, the parameters describing the train characteristics must be able to be modified. The modification can be done by a train driver via a data entry procedure or an interface must be present with a train control management system capable of providing this data.

This system must then indicate to the ATO onboard what the composition of the train is and whether brakes are isolated. Another possibility is the train control management system sending the applicable traction and braking models to the train. Grade of automation 3 or 4 system require additional functionality from the train control management system to interface with the door control system.

The driver (top left figure 24) has to be informed about the commands the ATO onboard is sending to the traction/braking system. After all in a grade of automation 2 system the driver is responsible for the safe movement of the train. An ETCS onboard system is equipped with a Driver Machine Interface (DMI). A digital displayed used to present ETCS information to the driver. ATO over ETCS expands the information presented on the DMI with ATO information of the current action ATO is performing. The driver determines if the actions taken by the ATO onboard are safe. If this is not the case a train driver will intervene by applying the brakes. Both the train driver and the ETCS onboard can override the control commands of the ATO Onboard. The ATO Onboard will automatically disengage whenever a brake command is given by either a train driver or the ETCS onboard.

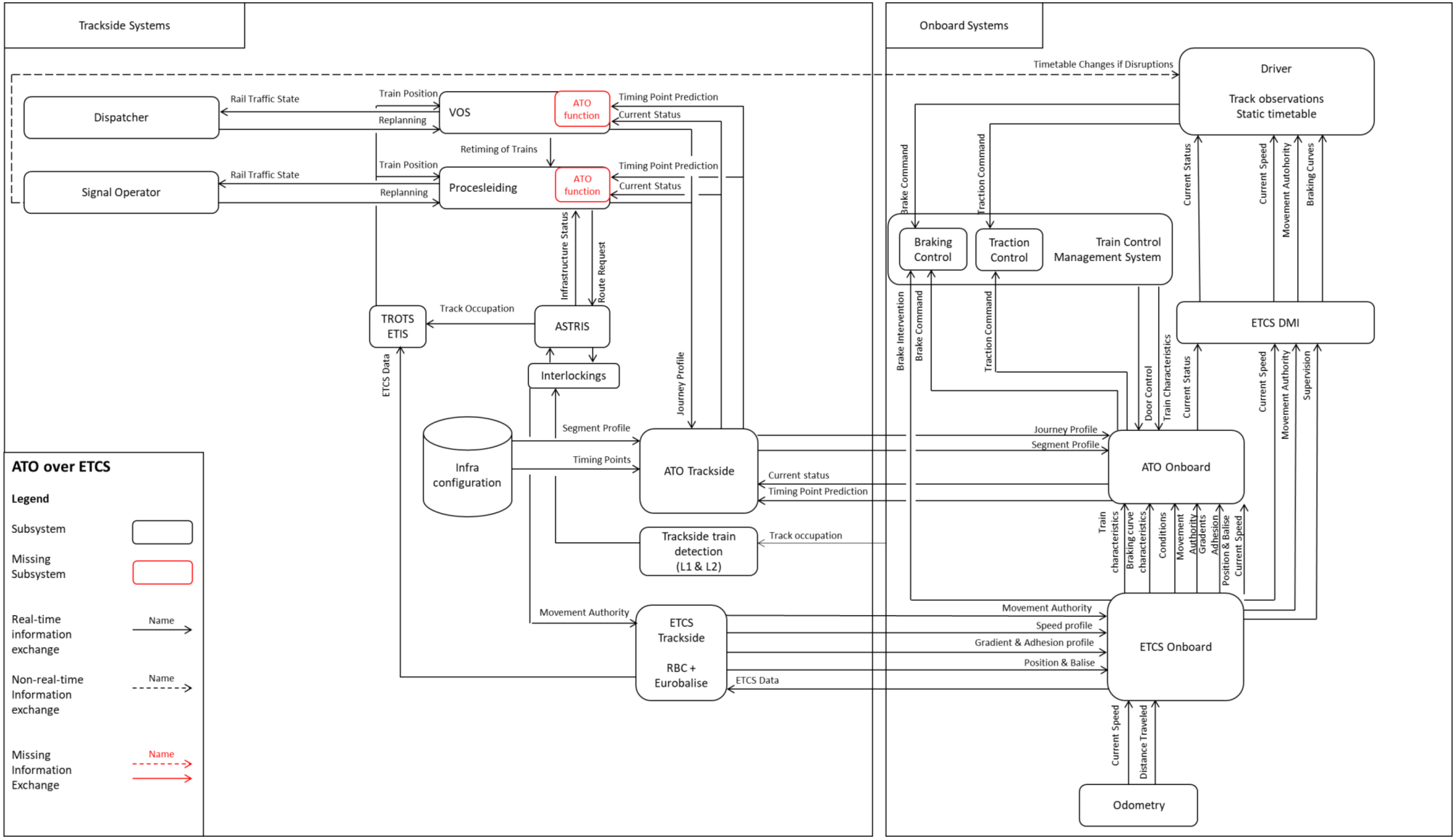


Figure 24 Conceptual model ATO over ETCS.

6. Analysis of ATO over ATBNG, According to the Generic ATO Model

This chapter presents the analysis of ATO over ATBNG according to the Generic ATO model presented in chapter 4. The ATO over ATBNG system is compared to the ATO over ETCS system which is presented in depth in chapter 5.

First in section 6.1 the ATBNG automatic train protection system is discussed. Secondly in section 6.1.4 the analysis of ATO over ATBNG is presented.

6.1 The ATBNG Automatic Train Protection System

Automatische Trein Beinvloeding Nieuwe Generatie is an Automatic Train Protection system featuring (van Leur, 1994):

- Braking curve supervision
- Speedsupervision
- Train stop fuction
- In cab signalling

6.1.1 Intermittent data communication and static speed profile

ATBNG features intermittent data communication, data is sent to the train at discrete points. These points are the ATBNG beacon locations.

The braking curve supervision and train stop functions require a speed profile, track characteristics, and train characteristics. The static speed profile and track characteristics are transmitted within the beacon message. Train characteristics are pre-programmed in the ATBNG onboard. The train driver can alter some train characteristics such as train length and number of isolated brakes.

The static speed profile is made up of a signal aspect dependent part and additional speed restrictions (ProRail, 2018d). The aspect dependent part contains three distance speed pairs with a corresponding gradient each. Figure 25 and Figure 26 visualize these three pairs for block beacons (beacons located directly at a signal) and intermediate beacons respectively (beacons located in the area between signals). Block beacons are indicated by a B in figures 24 and 25, intermediate beacons are indicated by a T in figure 25 and figure 26.

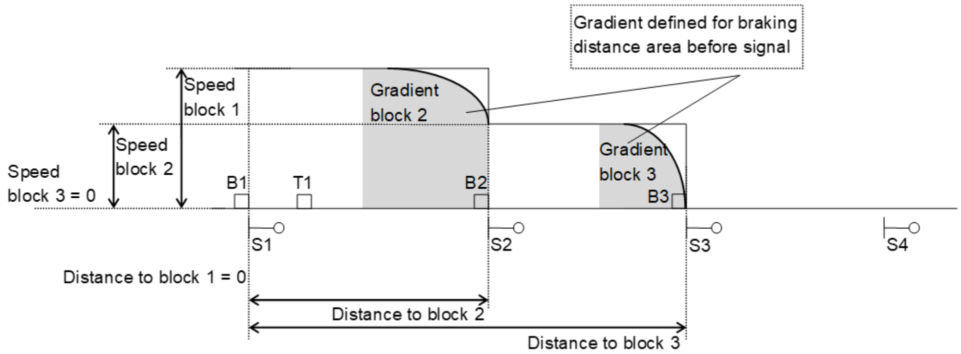


Figure 25 ATBNG distance-speed pairs for block beacons, (Simplified ProRail, 2018d)

Figure 25 shows the speed profile as it is defined at the location of a block beacon (a beacon located at a signal). The speed profile can be defined for the next three blocks according to speed-distance pairs. Each pair consists of a speed limit and the distance until the speed limit. Furthermore, a gradient is defined for the area of the braking distance before the signal.

Following fail safe principles, the speed limit of the third block (S3-S4) is 0, if ATBNG would miss a beacon message a train will automatically be stopped within its movement authority[4].

Figure 26 shows the speed profile as it is defined in an intermediate beacon (a beacon located in between signals). The train is located before the first block (at T1). Distant signals are always accompanied with an intermediate beacon.

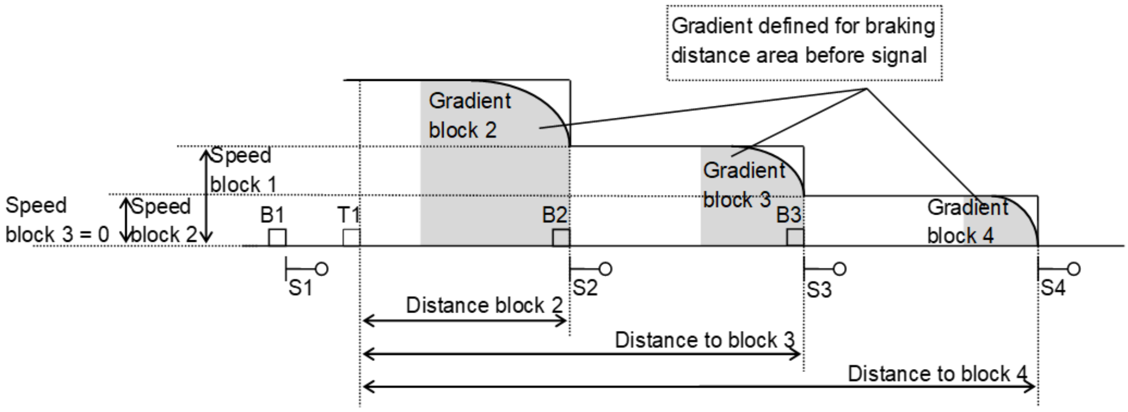


Figure 26 ATBNG distance-speed pairs for intermediate beacons, (Simplified ProRail, 2018d)

The static speed profile can be further elaborated with speed restrictions (ProRail, 2018d). For each speed restriction a speed, location, and gradient is set. The gradient is determined for the braking distance area before the speed restriction. Each beacon can contain two speed restrictions, additional beacons can be placed if more speed restrictions are required.

Moreover, ATBNG has provisions for the inclusion of temporary speed reductions in the static speed profile. However, due to the necessity to program a physical parameterplug, this feature is not used. (ProRail TB, personal communication, 2019)

ATBNG has provisions to take into account low adhesion conditions. However, it is up to the train operating company to implement this feature, therefore it cannot be assumed this is implemented. (ProRail TB, personal communication, 2019)

ATBNG calculates a dynamic speed profile based on the static speed profile and the braking characteristics. This dynamic speed profile takes into account the braking required to comply with an upcoming more restrictive speed. ATBNG monitors if the train speed is below the calculated braking curve and intervenes if the speed is above the braking curve. The use of individual train data (train length, maximum speed, braking capacity) could allow modern rolling stock to make use of its better braking performance (Van Leur, 1994). However, braking according to the ATBNG braking curve is not allowed. The next section explains in detail why this is the case.

The beacon message of a block beacon does not explicitly indicate the aspect of the signal, as it is not required for the functioning of ATBNG. Only red signals and flashing yellow signal aspects are indicated, for red signals it is indicated if the signal is a permissive red signal or a non-permissive red signal. Flashing yellow signals indicate running on sight, resulting in ATBNG imposing a speed limit of 40 km/h.

Intermittent automatic train protection systems have a common problem with respect to obtaining a new movement authority. It is assumed that the odometry system overestimates

[4] The concept of the movement authority is a concept of ETCS. Here it is used as the indication of a different beacon message which authorizes the train to proceed beyond the corresponding signal.

the passed distance, ensuring that the train is stopped before the end of the movement authority. However, this results in the train being unable to reach the next beacon. A new movement authority can only be received when the train reaches this next beacon. To solve this problems two solutions are implemented in ATBNG:

- NS’54 signals and release speed. ATNBG is always implemented on top of the NS’54 signalling system. Whenever a signal aspect changes from red to yellow/green, a train driver knows a new movement authority is available. The release speed “releases” the braking curve supervision whenenver the speed is below a certain threshold. This threshold is 15 km/h for permissive signals and 30 km/h for non-permissive signals (ProRail, 2018d). The ATBNG operatinal curve presented in figure 27 shows the effect of the release speed just before the red signal. The release speed is supervised by ATBNG
  The signals indicating a new movement authority and the release speed allow the train driver to slowly pass the beacon to receive the new movement authority.

- Antenna loops: ATBNG supports the implemention of antenna loops. These loops transmit the beacon message over a longer distance (up to two kilometers (ProRail, 2018d)) from the signal.

The implementation of a release speed in ATBNG can cause a train to pass a signal at danger. A trainstop function is implemented which stops the train whenever a signal at danger is passed. This is shown in figure 27 by the ATBNG operational curve extending beyond the signal. The area of release speed is limited. The train is stopped if the limit of the area of release speed is reached, even if no beacon is passed before this limit (ProRail TB, personal communication, 2019).

6.1.2 Difference between ATBNG operational envelope and NS’54 operational envelope

The operational envelope of the ATBNG automatic train protection system differs from the NS’54 signalling system operational envelope. Figure 27 shows the ATBNG operational envelope and the NS’54 operational envelope.

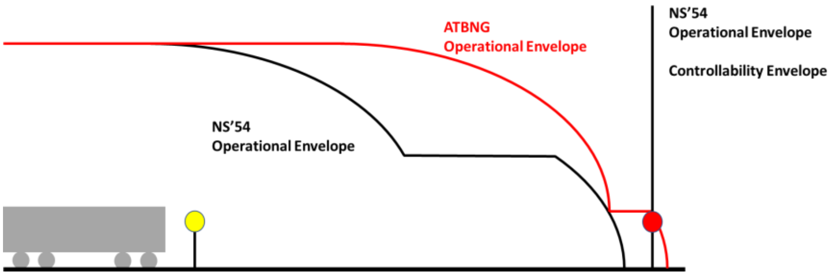


Figure 27 Visualization of delayed braking, black NS'54 braking curve and red ATBNG supervision curve.

ATBNG supervises a braking curve which is based on a static speed profile, track characteristics, and individual train characteristics. This results in an ATBNG operational envelope which is indicated in red in figure 27.

The black line represents the NS’54 signalling system operational envelope. The vertical black line indicates the end of the movement authority[5]. The black braking curve in figure 27 is the mandatory braking behaviour ordered by the NS’54 signalling system. Alongside the

[5] The concept of the movement authority is a concept of ETCS. Here it is used as the indication of a different beacon message which authorizes the train to proceed beyond the corresponding signal.

track red signals indicate the end of the movement authority. Prior to each red signal: a yellow signal is shown, a yellow signal orders a driver to brake and expect the next signal to order stop (red signal). This behaviour is mandated by Dutch law (Regeling Spoorverkeer, 2016). Particularly, relevant is §4 article 30 "*De bestuurder zet een door een sein opgedragen snelheidsverlaging in wanneer het eerste spoorvoertuig van de trein dit sein bereikt heeft*." (A train driver applies the brakes when the first vehicle of the train passes a signal which orders a speed reduction)

Figure 27 shows the difference between the operational envelope of NS'54 and ATBNG. The difference is caused by a difference in assumed train characteristics. The NS'54 signalling system must allow for sufficient braking distance for the worst performing train allowed on the Dutch network. ATBNG in contrast supervises the braking curve based on the actual braking performance of the particular train. This is generally better than the braking performance assumed for NS'54. Therefore the operational envelopes of NS'54 and ATBNG differ.

Train drivers must follow the operational envelope of NS'54. A so called 'delayed braking' i.e. braking according to the operational envelope of ATBNG is not allowed.

6.1.3 ATBNG in-cab signalling

The in-cab signalling feature of ATBNG functions with a dedicated display (ProRail, 2012) which indicates the current speed of the train, the goal speed, and the braking curve to the train driver using LED's. Figure 28 shows the analogue ATBNG DMI. The braking curve is only shown if the end of movement authority[6] is within braking distance. Furthermore, two matrix displays (yellow and red boxes below the speedometer in figure 28) present the operation mode (EG or NG), the goal speed (only NG mode), and fault codes to the train driver.

Figure 28. ATBNG DMI (Logiplus, n.d.)

6.1.4 The Automatische Rit Registratie protocol

The ATBNG onboard is connected to a Judicial Recorder Unit (JRU). The JRU records the status of the ATBNG onboard for judicial and accident investigation purposes. The JRU reads ATBNG status information using the Automatische Rit Registratie (ARR) protocol (ProRail, 2012).

ProRail already identified the ARR as a potential means for an ATO onboard system to read ATBNG status information.

[6] The concept of the movement authority is a concept of ETCS. Here it is used as the indication of a different beacon message which authorizes the train to proceed beyond the corresponding signal.

6.2 over ATBNG System Architecture

Figure 29 shows the system architecture of ATO over ATBNG. The ATBNG system takes the place of ETCS in ATO over ETCS. The system consists of three main subsystems. The ATBNG system, the ATO system and the train driver.

The analysis for the development of ATO over ATBNG starts with identifying the function of ATB in the system architecture. When the system architecture with ATBNG is compared to the system architecture of ETCS both ATBNG and ETCS have a similar place in the system architecture.

The ATO over ETCS system makes a distinct separation between the safety critical functions performed by ETCS and the non-safety critical functions performed by ATO. This separation is present in ATO over ATBNG as well. ATBNG performs the safety critical function of monitoring and enforcing the movement authority. ATO performs the non-critical function of driving the train.

The ATO over ATBNG system discussed in this master thesis is a GoA 2 system. The train driver is responsible for supervising the train, closing the doors, and controlling the train during emergencies.

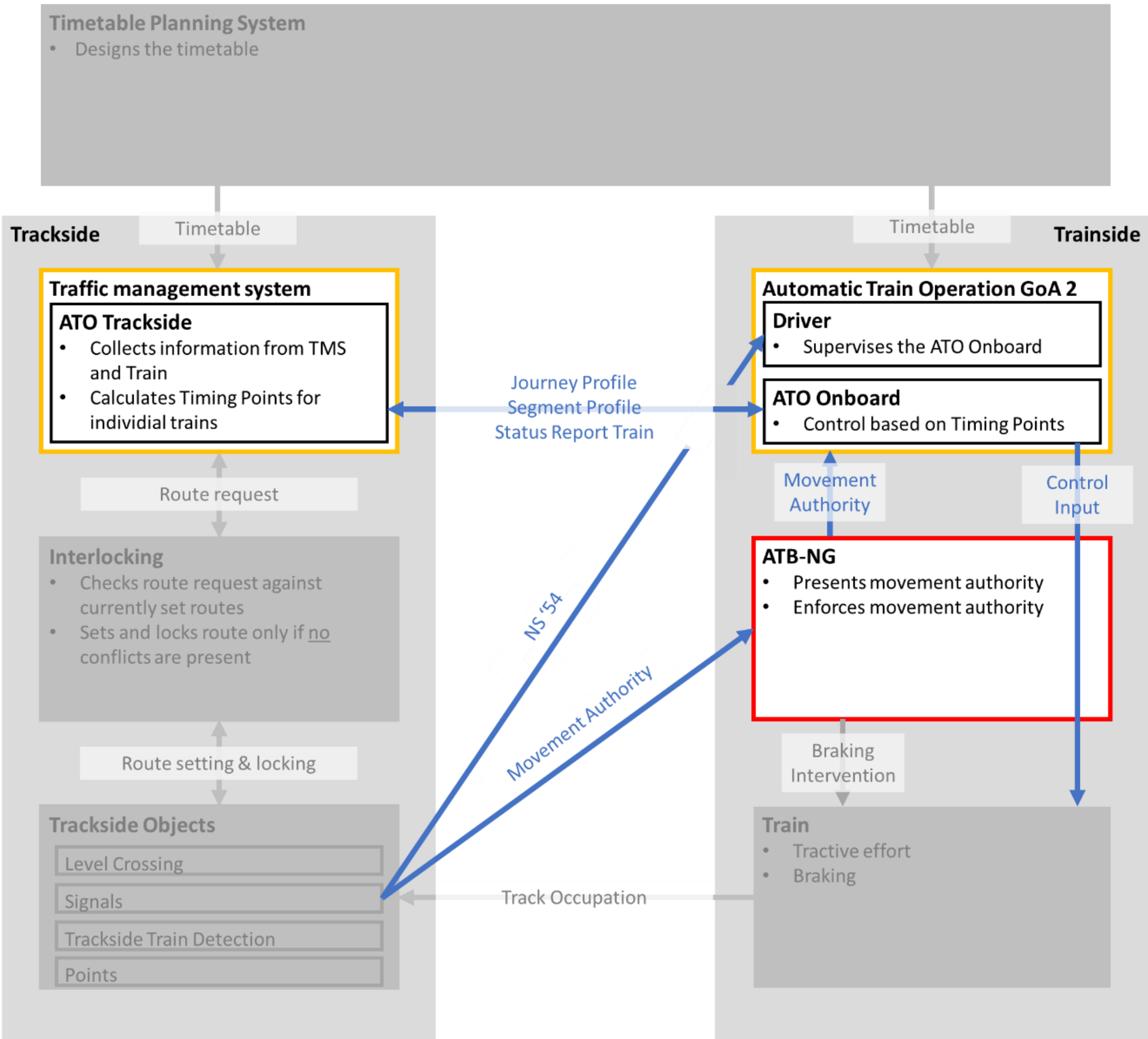


Figure 29 System Architecture ATO over ATBNG

6.3 Functions of ATO over ATBNG

The generic ATO model defines three functions trajectory generation, trajectory tracking, and traction/brake command generation. This section focuses on the mapping of the functions described in the generic model.

6.3.1 Trajectory Generation

The first function to be executed is the trajectory generation. First of all, this trajectory must, at all times, stay within the operational envelope imposed by NS'54 or ATBNG. Secondly, the trajectory should achieve the timetable when possible within the operational envelope of NS'54 or ATBNG.

However the analysis of ATBNG shows that the operational envelopes of NS'54 and ATBNG differ. If delayed braking is allowed ATO can use the speed-distance profile shown in figure 25 and figure 26 to determine the operational envelope.

If delayed braking is not allowed ATO must reconstruct the NS'54 operational envelope from ATBNG information. Here a difficulty arises, the beacon message of ATBNG does not explicitly contain the aspect of the corresponding signal. The aspect must be known in order for the ATO system to act correctly. Potential solutions have been discussed with experts at ProRail (S. Hoekstra, personal communication, 2019), (J. Heeren, personal communication, 2019), and Alstom (M. Hogenboom, personal communication, 2019). It must be stressed that this list is not complete, the aim is to present directions for solutions. The following potential solutions are identified:

Solution 1 Conservative braking

The conservative braking strategy consists of ATO to start braking at a sufficiently large distance before the red signal to ensure braking starts before the yellow signal as well.

This strategy requires the ATO onboard to have information about the end of the movement authority. The ATO onboard reads movement authority information from the ATBNG onboard via the ARR protocol.

The ATO system shall react as follows on reading new ATBNG beacon information:

1. ATO onboard monitors distance to goal speed.
2. ATO onboard drives closer to the goal and starts braking when distance to goal speed becomes equal to the determined maximum yellow signal – red signal distance.

This strategy requires a braking distance to be determined, in order to ensure braking is started before yellow signals. Therefore, the maximum must be determined. ATO always starts braking at this maximum distance.

Whenever a yellow signal is located closer to the red signal than the block size ATO will start braking earlier than necessary, this is visualized in figure 30. This reduces the performance of ATO because ATO drives at a lower speed for longer than required.

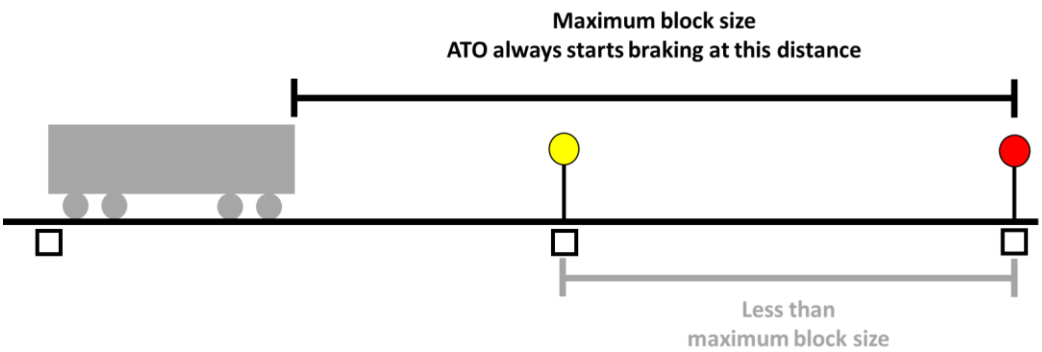


Figure 30 ATO always starts braking at maximum block size distance even if the local distance is less than the maximum distance.

Furthermore, if the movement authority is expanded and no beacon is present to send the new movement authority to the train before the train reaches the maximum yellow signal – red signal distance, ATO will brake unnecessarily, reducing the performance of ATO.

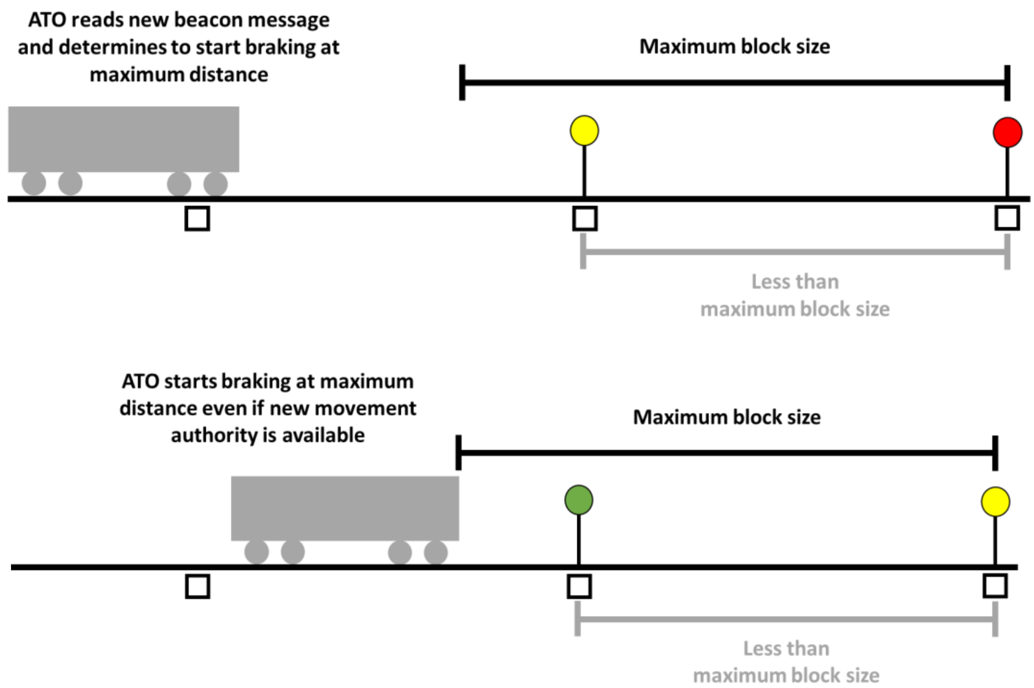


Figure 31 If a new movement authority is available but no beacon is present to send the new movement authority to the train before the block size distance is passed ATO will brake unnecessarily.

Solution 2 Braking based on infrastructure description and ATBNG braking curve

The ATO system reads the goal speed and the distance to this goal speed from the ATBNG system. This information can be combined with a map of infrastructure elements (such as signals and speed signs) and their location to determine the signal/speed sign ordering the movement authority.

If the goal speed requires the train to brake, the ATO system can determine the signal or speed sign which orders the train to brake using the infrastructure measurement and distance to goal speed. A margin must be kept considering inaccuracies in the infrastructure measurement and odometry.

The ATO system shall react as follows on reading new ATBNG beacon information:

1. ATO monitors the ATBNG goal speed and distance to goal speed.
2. For a goal speed which requires ATO to brake, ATO determines which signal or speed sign orders the train to brake based on the map of infrastructure elements.
3. The ATO onboard monitors the location of the train and starts braking at the location of the sign or signal which orders the train to brake.

Speed reduction signs have both a static location and a static order. Therefore, these could be directly included with an order for the ATO onboard in the infrastructure map.

Solution 3 Lookup signal aspect from beacon message and additional information (PDL, OBE, OS – diagrams)

Another strategy is to derive the signal aspect based on the beacon message combined with another set of information.

Beacon messages are prespecified based on the signal aspects that the corresponding signals can show. Therefore, the signal aspect of a signal can be determined based on the beacon messages of corresponding beacons. However, an analysis should be made to ensure that a beacon message should lead to an unique signal aspect.

The ATO system shall react as follows on reading new ATBNG beacon information:

1. The ATO onboard looks up the signal aspect corresponding to the beacon message in a database created from PDL diagrams.
2. If the signal aspect contains a brake order, the ATO onboard monitors the distance to the signal (via GPS or ATBNG updates) and starts braking when the signal is passed.

Solution 4 Use of the BGACT parameter

M. Hogenboom (personal communication, 2019) mentioned that the BGACT parameter can be used to determine if a yellow signal aspect is shown. The BGACT parameter activates the goal speed indicator inside the train. The goal speed indicator needs to be activated when a yellow signal aspect or speed reduction sign is passed. Therefore, this parameter could also be used to indicate to the ATO system when a yellow signal/speed reduction sign is passed.

However, the BGACT parameter is part of the latest version of the ATBNG system. Thus, this strategy can only be used for signals equipped with the latest version of ATBNG.

The ATO system shall react as follows on reading new ATBNG beacon information:

1. The ATO onboard checks the BGACT parameter from the received beacon information.
2. If the BGACT parameter indicates a yellow signal aspect or speed reduction sign, the ATO onboard starts braking.

Speed reduction signs are not necessarily equipped with an ATBNG beacon. If this is the case the last beacon before the speed reduction sign is equipped with BGACT. However this results in ATO braking before the location of the speed reduction sign, reducing performance because ATO runs at a lower speed for longer than required.

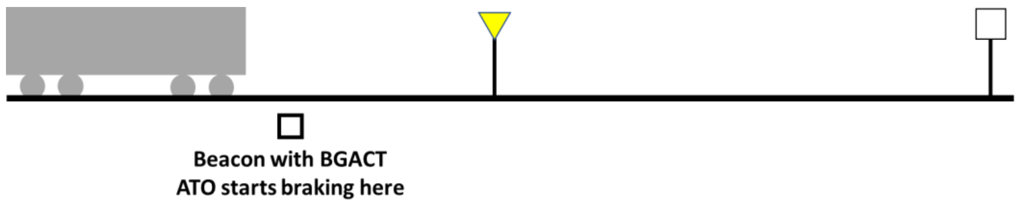


Figure 32 If a speed reduction sign is not equipped with an ATBNG beacon BGACT is implemented in the first beacon before the sign. In this case ATBNG will start braking before it is required.

Solution 1 has limited performance for blocks shorter than the maximum block length. Moreover, shorter blocks are often chosen at locations where headways are critical. Solution 4 has limited performance for speed reduction signs and the BGACT parameter is part of the latest version of ATBNG. Not all beacons are equipped with the BGACT parameter. The most promising solutions are solutions 2 and 3 because these solutions do not have the limitations described for solution 1 and 4. Both solutions require the ATO onboard to receive additional information from the traffic management system to determine the signal and sign positions.

Figure 33 presents an overview of the required information to construct the NS'54 operational envelope. It is essential for the ATO system to know the signal aspect, if delayed braking is not allowed. In order to derive the signal aspect, the ATO onboard must know the current beacon message and a database which links a beacon message to a signal aspect. The permitted curve by ATBNG is defined by the distance speed pairs mentioned in section 5.1, which must be known to construct the permitted curve. The signals announcing a static speed restriction must be added to the segment profile.

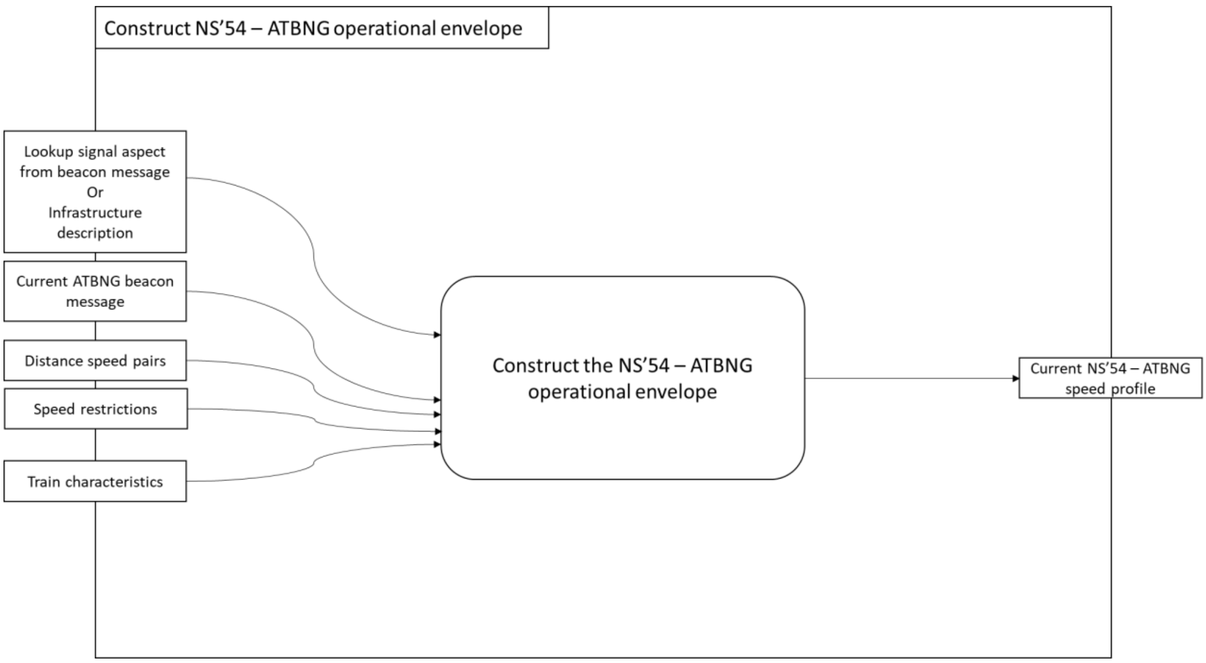


Figure 33 Overview of Construct NS'54 - ATBNG operational envelope function.

Secondly, the trajectory must adhere to the timetable whenever allowed by the signalling operational envelope. This does not differ from ATO over ETCS. Therefore, ATO over ATBNG can use the systems developed for the ATO over ETCS system. The ATO trackside sends a journey profile containing timetable described by timing points and the route described by a list of segments to be passed.

6.3.2 Trajectory Tracking

The ATO over ATBNG must track its trajectory against the trajectory generated by the trajectory generation function. This does not differ from the ETCS case. Therefore, no changes have to be made.

6.3.3 Traction/Brake Command Generation

The traction/brake command generation function does not differ from ATO over ETCS.

6.4 Input information, ATO over ATBNG

The generic ATO model defines the input information required for ATO. This section uses the structure of the generic model to discuss the input information of ATO over ATBNG.

6.4.1 Safety Envelope

The relevant safety envelope depends on whether delayed braking is allowed or not. The ATBNG operational envelope is the relevant safety envelope if delayed braking is allowed. The NS'54 operational envelope is the relevant safety envelope if delayed braking is not allowed.

ATO can read the ATBNG operational envelope by reading the goal speed and distance to goal speed of ATBNG via the ARR protocol.

Deriving the NS'54 operational envelop is more complex. To derive this operational envelope information from different sources must be combined:

- ATBNG onboard
    - Latest ATBNG beacon message
    - Goal speed; distance to goal speed
- ATO trackside
    - Database linking ATBNG beacon messages to signal aspects
    - Infrastructure description including signal and sign locations

Speed restriction announcement signs are not included in the ATBNG information. This information must be available to allow the train to brake at the location of the signal announcing a speed restriction.

The beacon message database and infrastructure description are static information. Therefore, it could be incorporated into the segment profile. The segment profile is then updated as with ATO over ETCS. Before a run the segment profiles of the relevant railway lines are sent to the ATO onboard. The journey profile then refers to specific segment profiles to give a specific route. To indicate that the beacon message database must be added to the information send from ATO trackside to ATO onboard figure 35 indicates the beacon message database as separate from the segment profile.

6.4.2 Timetable

The journey profile sent from the ATO trackside to the ATO onboard describes the timetable. ATO over ATBNG can use the same information model to provide timetable information to the ATO onboard.

The current timetable itself originates from the ProRail traffic management system. Similar as with ATO over ETCS a connection must be made between the ProRail traffic management system and the ATO trackside.

6.4.3 Route Characteristics

The segment profile sent from the ATO trackside to the ATO onboard provides an infrastructure description for ATO over ETCS. ATO over ATBNG can use the ATO over ETCS specifications in this regard.

However, some modifications must be made:

- The location of trackside elements shall be based on the positioning reference used by ATBNG
- Signal locations shall be added to the segment profile
- A database linking ATBNG beacon messages to signal aspects shall be added.

The analysis of ATO over ETCS shows that the route characteristics originate from the traffic management system. Thus, ATO over ATBNG can use the specifications of ETCS in this regard.

6.4.4 Train Characteristics

The ATO onboard can read some train characteristics from the ATBNG onboard using the ARR protocol. These include:

- Number of isolated brakes
- Train length

This information can be read by the ATO onboard using the ARR protocol. The ATO onboard can use this information to determine the correct traction and braking model.

However, ATBNG cannot provide the traction, resistance, and braking model of the train. The Train Control Management System (TCMS) is capable of providing the traction and braking model according to an interview with Stadler (Stadler, personal communication, 2019).

Another solution would be to preload the ATO onboard with traction and braking models. The ATO onboard can then determine the correct models to be used based on ATBNG train characteristics information.

6.5 Output information, ATO over ATBNG

The ATO model also defines a set of information outputted by the ATO onboard. This section describes which systems use the information output of the ATO onboard.

6.5.1 Current Status

The current status of the train consists of the current action ATO is taking (accelerating, cruising, coasting, braking), the current location of the train and the current speed of the train.

The current action of ATO must be communicated to the train driver. ATO over ETCS uses the digital ETCS driver machine interface (DMI) to present the information to the train driver. ATBNG is equipped with an dedicated DMI. It is not a screen which can flexibly show different images. Without modifications to the ATBNG onboard system the DMI is not capable of presenting the current action ATO is taking to the train driver. Therefore, a new subcomponent shall be introduced which takes the role of informing the driver of the current status of the ATO system. Figure 38 presents this component as ATO DMI. This component can be a simple screen connected to the ATO onboard.

Furthermore, the current status including the current location and speed of the train is sent to the ATO trackside. The ATO trackside relays this information to the ProRail traffic management system. The ProRail traffic management system is currently not capable of presenting this information to signal operator or dispatcher. Figure 38 presents a new ATO function which shall be added to procesleiding and VOS and is capable of presenting this information.

6.5.2 Timing point prediction

The ATO onboard makes a prediction of the arrival time at upcoming timing points, this is called the timing point prediction. The ATO onboard sends this information to the ATO DMI and the ATO trackside. The ATO trackside relays this information to the ProRail traffic management system. The timing point prediction must be presented to the train driver and the signal operator at the ProRail traffic control centre.

The ATO DMI and ATO function described in the previous section shall be capable of presenting the timing point prediction to its respective users.

6.5.3 Traction/Brake Command

The traction and brake commands are sent to the traction and brake system in the same manner as with the ATO over ETCS system.

6.6 Findings: The ATO over ATBNG system

This section summarizes the findings of the previous sections with respect to the implementation of ATO over ATBNG for testing purposes. The starting point is the current system of manual driving over ATBNG presented in figure 34. Step by step additional subsystems are added concluding in a proposed configuration of ATO over ATBNG system.

The resulting SysML model presented in figure 37 presents the ATO over ATBNG model. The components of the system are shown by means of boxes. The information exchange between the systems is shown as well by the arrows between the boxes.

6.6.1 Current system manual driving

The ProRail traffic management system is presented in the upper left side of figure 34. Signal operators and dispatchers continuously monitor the traffic situation using information provided by procesleiding and VOS respectively.

Procesleiding presents the signal operator with a schematic overview of the infrastructure, routes and train positions. VOS presents the dispatcher with a time distance diagram of train paths delays are.

The signal operator is tasked with ensuring the traffic plan is conflict free. Small conflicts and modifications are solved by the signal operator alone. Larger conflicts and modifications resulting in a different train order on the open track are solved by the signal operator after consultation and approval of the dispatcher. The automatic route setting system of Procesleiding automatically sets routes based on the current traffic plan. Routes are set if the corresponding train passes a trigger point within a set window. ASTRIS and interlockings process the route request of Procesleiding and set the route if no conflicts are present.

The route set by the traffic management system is communicated to the train driver by NS'54 signals. The train driver follows the orders given by the NS'54 signals. The ATBNG onboard receives information about the set route from the ATBNG beacon. The resulting speed, and braking curve are presented to the driver using the analogue ATBNG DMI. The train driver receives information on the braking curve from ATBNG Information about upcoming goal speeds and the distance to this goal speed are presented to the driver as well. However, a train driver is not allowed to act based on ATBNG braking curves, signal orders takes precedence. Within the operational envelope given by the NS'54 signalling system the train driver operates the train according to a printed out static timetable.

The ATBNG continuously monitors maximum speed, the braking curve and the end for the movement authority and intervenes whenever the train exceeds the limits of the ATBNG operational envelope.

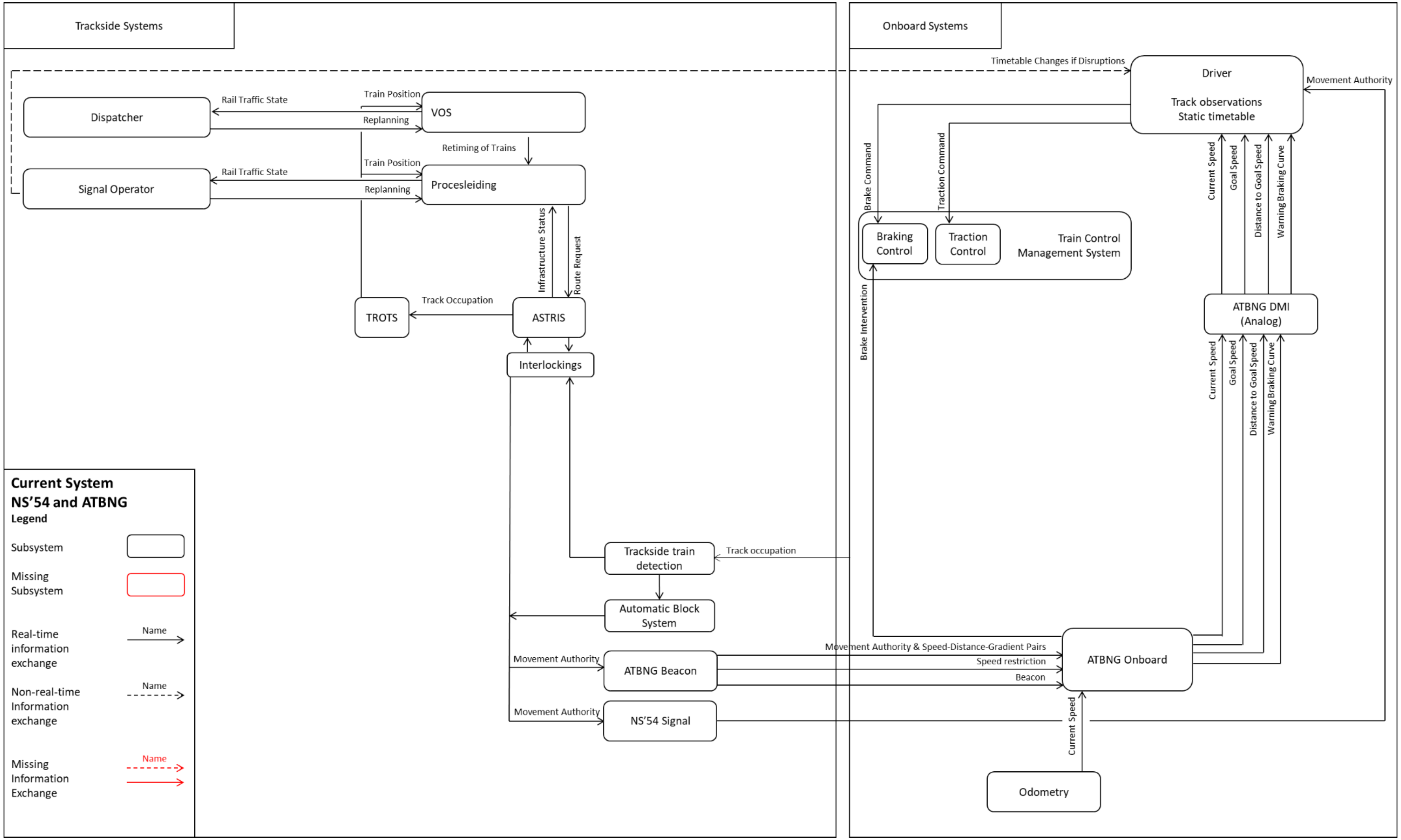


Figure 34 Conceptual model manual driving over ATBNG

6.6.2 Adding ATO to the ATBNG system

The first step to add ATO to the current system is adding the basic ATO system. This consists of the ATO trackside and the ATO onboard, this is presented in figure 36.

The ATO trackside sends a journey (timetable & route) and segment profile (infrastructure description) to the ATO onboard.

The ATO onboard performs the functions of trajectory generation, trajectory tracking, and generating the traction/brake commands.

The ATO onboard sends a current status and timing point prediction to the ATO trackside. Traction and brake commands are sent to the traction and braking systems respectively.

6.6.3 Connecting the ATO onboard with the ATBNG onboard

The ATO onboard can only run according to the journey profile if the journey profile fits within the safety envelope. The safety envelope is either made up of the ATBNG operational envelope if delayed braking is allowed or the NS'54 operational envelope if delayed braking is not allowed.

Nevertheless, an interface with the ATBNG onboard system is required. The ATBNG system is equipped with an Judicial Recorder Unit (JRU), which records messages from the ATBNG onboard. The JRU interfaces with the ATBNG onboard using the ARR protocol. The ATO onboard can use this protocol to read messages from the ATBNG onboard system, as shown in figure 35.

The ATO onboard reads the static speed profile, gradients, next beacon number, current speed, distance travelled since last balise, and the beacon message. The ATO onboard can determine the ATBNG operational envelope from this information. Additional information is required from the traffic management system (via the ATO trackside) to determine the NS'54 operational envelope. Figure 35 presents this additional information with a red arrow from ATO trackside to onboard.

The function of ATBNG does not change. ATBNG performs the safety critical function of supervising the safe movement of the train.

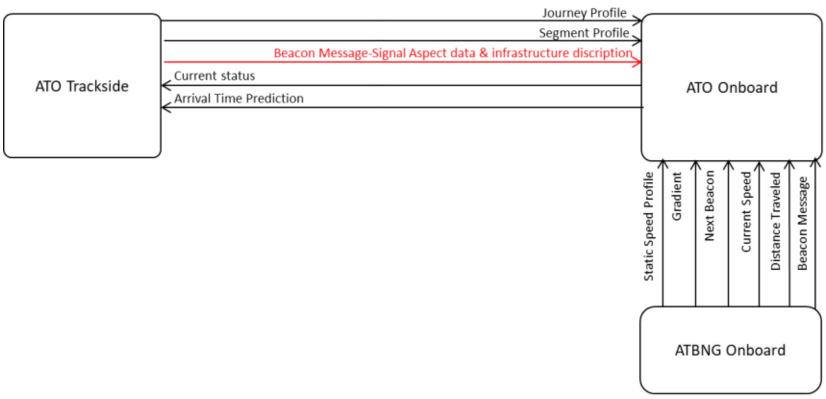


Figure 35 Connecting the ATO onboard with the ATBNG onboard

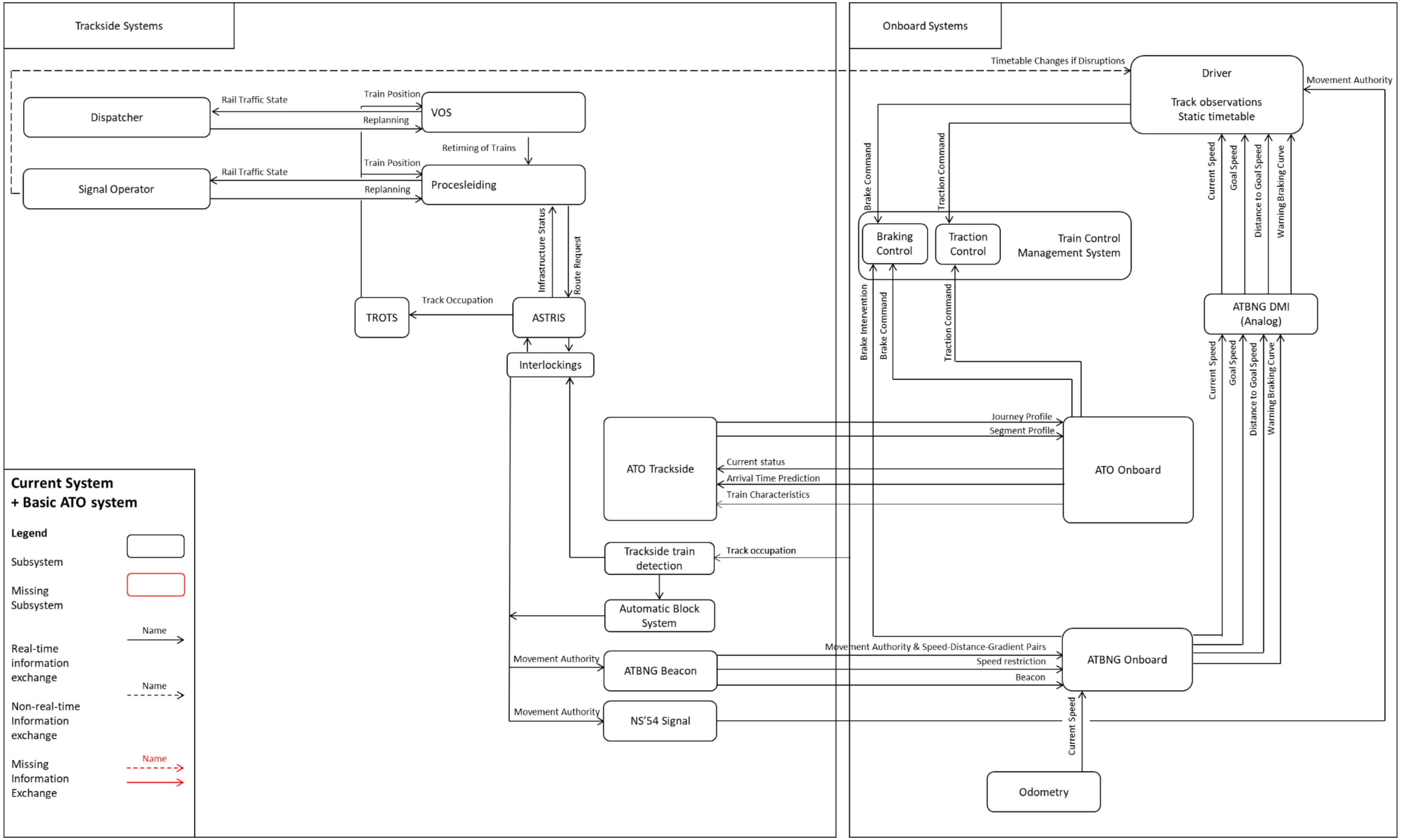


Figure 36 The ATO trackside and ATO onboard added to the current system.

6.6.4 Connecting the ATO trackside to the ProRail traffic management system

The ATO trackside system must be connected to the ProRail traffic management system to collect and distribute the information sent to and received from the ATO onboard.

The segment profile contains static infrastructure information. This information is available within the infrastructure configuration database. Information linking the beacon message of ATBNG with the specific signal aspect is not yet available within the ProRail infrastructure configuration. This information is available in PDL diagrams and must be added to the infrastructure configuration. The ATO trackside then reads this information from the infrastructure configuration.

The journey profile is dynamic and must therefore be delivered in real time from the ProRail traffic management system. Routes are planned and set using Procesleiding. Therefore, the ATO trackside must read the journey profile from Procesleiding. This includes both the arrival times at timing points and a list of segment profiles which indicate the route.

The current status information and timing point prediction must be sent to the ProRail traffic management system. Both the signal operator and the dispatcher can make use of this information to support traffic management interventions. However, the ProRail traffic management system is currently not capable of processing this information. A new ATO function for both procesleiding and VOS will need to be introduced which shall be capable of presenting the timing point prediction and the current status information to the signal operator and dispatcher respectively. This function is indicated by a red box within Procesleiding and VOS.

6.6.5 Providing information to the DMI

Current status information must be presented to the train driver. The ATBNG DMI is analogue and not capable of presenting this information to the train driver. A new ATO DMI shall be added to the ATO over ATBNG system which is capable of presenting the current status information to the train driver. This component can just be a simple screen.

Modifications to the ATBNG DMI are unwanted because the DMI is part of the safety systems. If modifications are made it must be proven that the functionality of the safety system is not impacted.

Figure 37 presents the ATO DMI by the red box between the ATO onboard and the train driver.

6.6.6 Train characteristics

The ATO onboard must be provided with train characteristics which allow the ATO onboard to determine the traction, braking and resistance characteristics.

Train characteristics including traction, resistance, and braking model can be provided by the train control management system (TCMS). Furthermore, the ATO onboard can read train length and the number of isolated brakes form the ATBNG onboard.

Therefore, there are two possibilities. Either the ATO onboard can read the current traction, resistance, and braking models from the TCMS. Or use the ATBNG information to determine the correct set of models from preloaded models in the ATO onboard. The connection required to read the current models from the TCMS is presented in the lower left corner of figure 36.

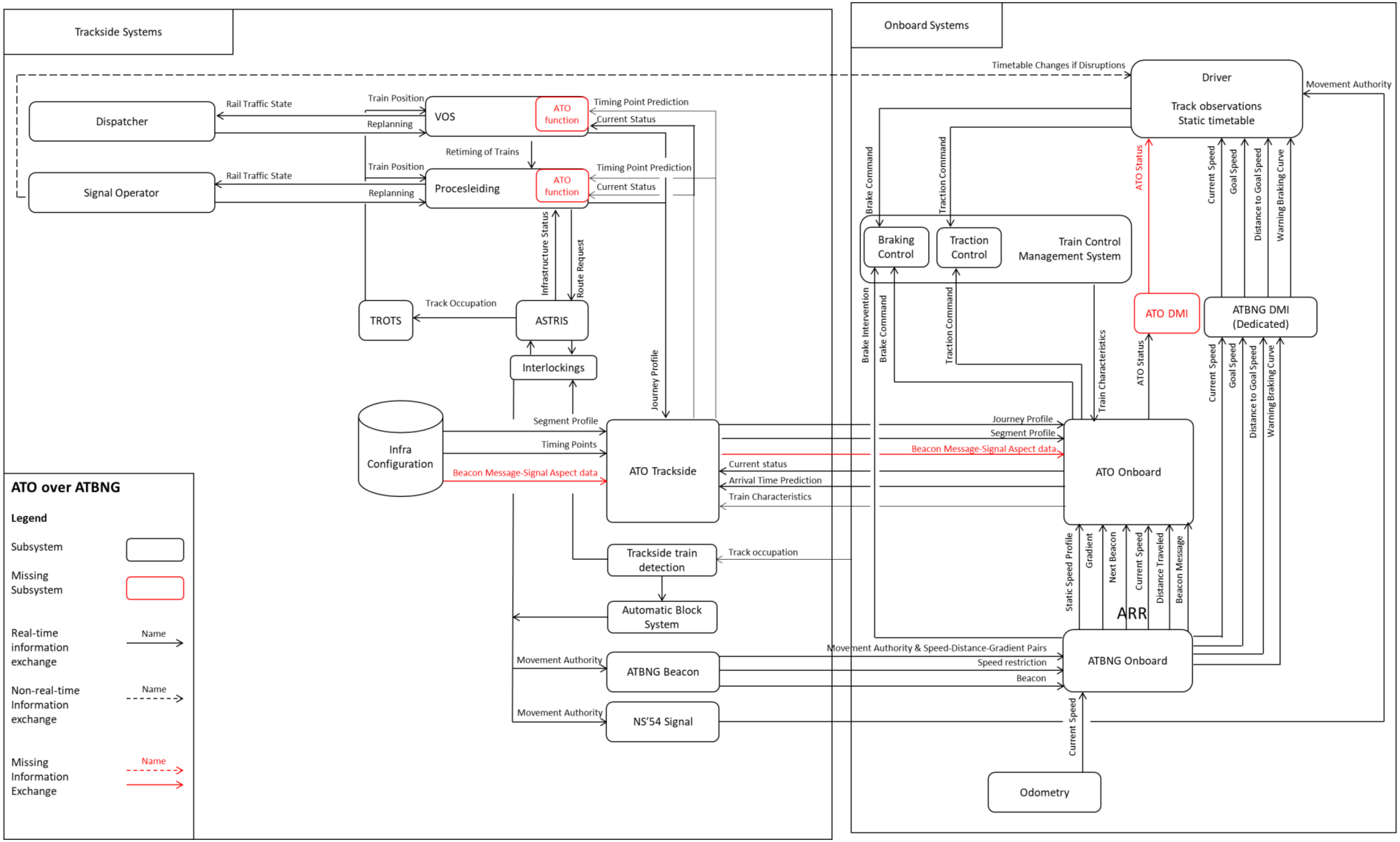


Figure 37 Conceptual model ATO over ATBNG.

7. Validation of the ATO over ATBNG conceptual model

The validation of the conceptual model for ATO over ATBNG presented in chapter 6 is discussed in this chapter. Three cases are discussed. First a general description of the case is given. Thereafter, the case is analysed using the ATO over ATBNG conceptual model. For the traffic management case is also worked out using the current and ATO over ETCS system. To gain insight in the new traffic management possibilities and determine the difference with ATO over ETCS.

7.1 Choice of case studies

Three case studies are chosen, a traffic management case, a red signal approach case, and a level crossing approach case.

One of the goals of this study is to determine if the information provided by ATO can be used for traffic management interventions. The first case is a situation whereby a local train exiting a single track section is delayed. This delay causes a conflict with an express train which is about to enter the single track section. The required steps to execute a traffic management intervention are discussed taking into account the findings of interviews with signal operators. The main findings of the interviews are presented in section 7.2.1.

It is essential that ATO over ATBNG is capable of stopping in front of a red signal. Therefore, this case is chosen as a second case.

Level crossings are seen as high risk areas (ProRail, 2019e). Therefore the level crossing approach case is chosen as the third case.

7.2 Case 1: Traffic management with delay present

During the 1990's the regional railway line Groningen-Leeuwarden has been equipped with Automatische Treinbeïnvloeding Nieuwe Generatie (ATBNG). Railway lines marked green in figure 38 are equipped with the ATBNG automatic train protection system.

Figure 39 shows the railway line between Groningen-Leeuwarden. This railway line is a combination of double track and single track. All of the stations have two platform tracks, except for Leeuwarden Camminghaburen which has only 1 platform track. The figure indicates the presence of station Leeuwarden Achter de Hoven, but this station has been closed in 2018 (OVPro, 2018).

The current timetable contains in each hour two local trains, one express train, and during rush hour one shuttle between Groningen and Zuidhorn.

- Express train — stops in Groningen – Buitenpost – Leeuwarden v.v
- Local train — Stops in all intermediate stations between Groningen-Leeuwarden
- Rush hour shuttle — During rush hour one train an hour from Groningen-Zuidhorn v.v

Currently work is underway to expand the infrastructure, allowing for one additional express train each which will have an intermediate stop in Faenwälden. No overtaking takes place on this railway line.

Figure 38 Automatic Train Protection systems in the Netherlands, green indicates ATBNG (ProRail, 2019a)

Figure 39 Groningen-Buitenpost-(Leeuwarden) railway (Sporenplan.nl, n.d.)

The track layout of the railway combined with the current timetable limits the types of interventions which can be made by the traffic management system.

- **Reordering**
  The order of the trains is set at the departure from the terminal stations of Groningen and Leeuwarden, as there is no overtaking. The track layout of the railway lines limits the possibilities for reordering. The crossover switches located before and after Buitenpost can allow overtaking. However, in the current timetable trains pass at Buitenpost which makes a reorder intervention on Buitenpost unlikely.
  Reordering cases are not considered because it has been determined that there are limited possibilities for reordering.

- **Rerouting**
  Alternative routes are scarce, the railway line does not run through large station areas. Furthermore, crossover switches on the double track section are only present around Buitenpost. The stations of Hurdegaryp and Zuidhorn are double track station located on the single-track section, changing the arrival platform can speed up the arrival as the switch can be passed straight instead of diverging.
  Because of the limited possibilities for rerouting cases, rerouting cases are not considered.
- **Retiming**
  Retiming can be applied to prevent unplanned stops for the express train on this route. An advantage of preventing unplanned stops is the reduction of delay propagation in the opposite direction. The case in this research considers a retiming operation. It is expected that this retiming results in a slowdown of the considered train. Retiming resulting in an extension of the dwell time is not considered in this research.

Figure 41 presents the 2019 off-peak timetable. The rush-hour shuttle between Groningen-Zuidhorn v.v. is not included in this diagram. The 2019 timetable has four potential conflict points. These potential conflict points are indicated in figure 41 and numbered. Table 1 discusses the type of conflict. The conflicts are located between Hurdegaryp and Feanwälden and between Buitenpost and Groningen. Both conflict types consist of a train which is scheduled to enter a single track section just after a train has exited the single track section. If the train exiting the single track section is delayed by a certain critical delay a conflict arises with the train entering the single track section.

Potential conflicts at the meeting point in Zuidhorn and Hurdegaryp have not been taken into account. Delays will result in trains extending their dwell time as trains cannot be set before the route is set. The route can only be set after the conflicting train has entered the station.

Conflict	Conflict type	Critical delay	Location
1	Local train delayed by more than critical delay, express train cannot enter single track section	3 minutes	Veenwouden
2	Local train delayed by more than critical delay, express train cannot enter single track section	3 minutes	Grijpskerk Aansluiting
3	Express train delayed by more than critical delay, local train cannot enter single track section	3 minutes	Grijpskerk Aansluiting
4	Express train delayed by more than critical delay, local train cannot enter single track section	2 minutes	Veenwouden

Table 1 Conflict types in current timetable Groningen-Leeuwarden V.V.

In this study case conflict 2 has been chosen to validate the ATO over ATBNG conceptual model. This specific case has been chosen because:

- Location is within current scope of ATO test runs. The test runs of ATO over ATBNG take place between Groningen and Buitenpost.
- The express train is hindered by the local train.

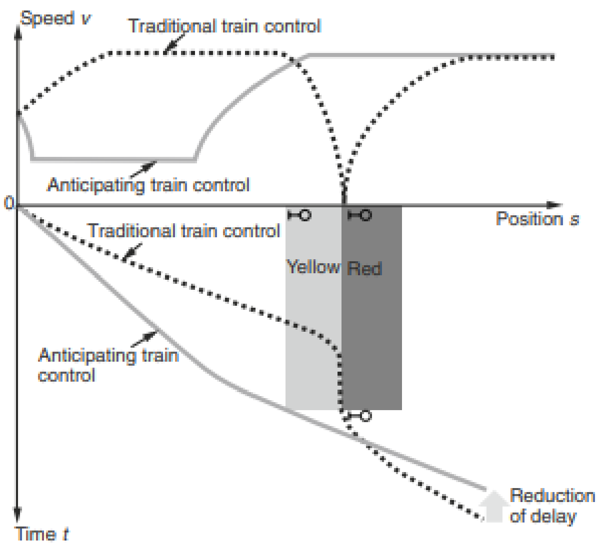


Figure 40 The principle of anticipating train control (Albrecht, 2009).

Conflict 2 is located at timetable point Grijpskerk Aansluiting. The case presented above is described for three different situations. For each situation the steps required to retime the express train in order to prevent an unplanned stop at Grijpskerk Aansluiting are discussed.

This unplanned stop will result in additional delay and additional energy consumption. Albrecht (2018) shows that anticipating train control reduces energy consumption and increases passenger comfort by avoiding unplanned stops. Figure 40 shows that anticipating train control works by slowing down the train before the conflict point. The train should re-accelerate then such that the conflict point is traversed just after the conflict is resolved. For certain situations a reduction of delays is also possible. The consequences of the unplanned stop at Grijpskerk Aansluiting consisting of additional energy consumption, reduced passenger comfort, and potential additional delay can thereby be mitigated by anticipating train control.

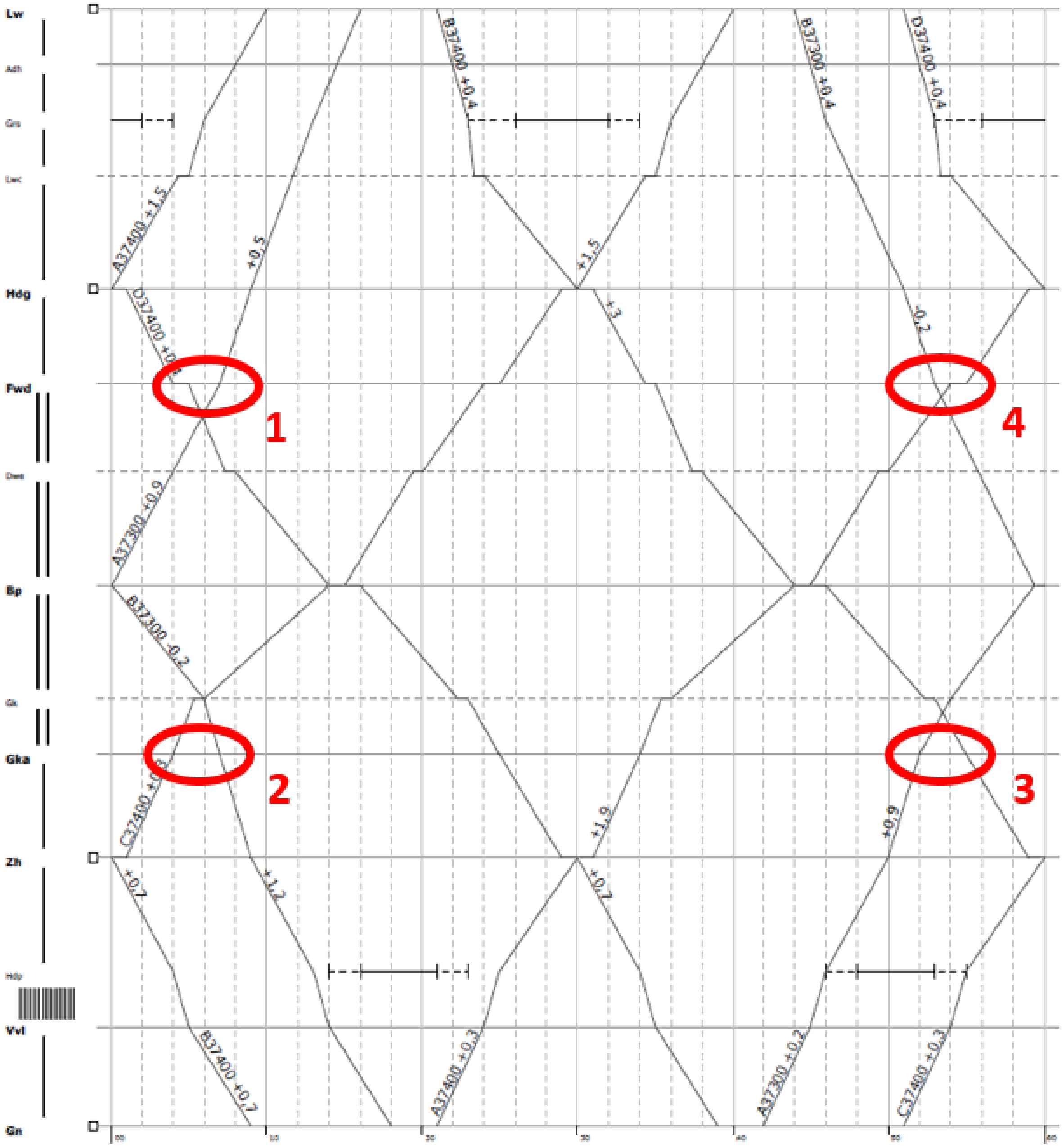


Figure 41 Time-distance diagram Groningen-Leeuwarden Timetable 2019 (ProRail, 2018f)

7.2.1 Interviews with Signal Operators

G. Knigge (personal communication, 2019) and B. Willemsen (personal communication, 2019) have been interviewed to gain insight from the perspective of the signal operator. The interviews aimed to get insight in the task, the information need, and potential of ATO to support the task of the signal operator. This section presents the main findings.

The task of the signal operator

Signal operators have two main task a logistical task and a safety task. The logistical task comprises of processing delays and changes to the timetable. The signal operator must consult the dispatcher if an intervention by the signal operator would result in a change in the order of trains on the open track[7]. The safety task comprises of taking safety measures during disruptions and emergencies.

The safety task consists of a number of steps:

- Alerting of train drivers
- Recalling of signals
- Turning off automatic route setting
- Inform neighbouring signal operators
- Set restrictions on signal and switch operation

The information need of signal operators

Signal operators receive information about the rail traffic state by the Procesleiding system. The following information is shown by Procesleiding:

- A schematic view of the infrastructure including the track layout, switches, signal locations, platforms, and electrification of tracks.
- Set and locked routes.
- Block occupation. The TROTS system links train numbers to occupied block, thus the signal operator can see which block is occupied by which train. Therefore, the location of the train is only known on the level of block sections.
- The Planscherm shows the signal operator a list of route steps to be set. For each step a train number, a origin track, a destination track, a plan time, a setup time, a delay measurement and the location of the delay measurement.

Two main shortcomings of Procesleiding are mentioned. First, delays shown by Procesleiding are based on a measured delay. The measured delay and the location where this delay was measured are presented to the signal operator. The signal operator relies on his/hers experience to estimate how the delay will develop. This is more difficult for trains further away from the control area and if larger stations are in between the control area and the delay measurement location. Secondly, the position of trains is presented on the block section level and speed information is not known. Accurate position and speed information can help a signal operator with his/hers situation awareness. Better situation awareness helps the signal operator to prioritize actions.

The potential of ATO to support the task of the signal operator

ATO can be an enabler for functions which can support the task of the signal operator. To implement these functions modifications to the traffic management system are required as well.

The timing point prediction made by the ATO system provides a prediction of the arrival time at upcoming timing points. This enables the measured delay to be replaced or expanded with the a predicted delay based on the timing point prediction of ATO. This helps the signal operator by reducing the need for estimating a delay based on experience. For delays measured at a large distance from the control area this can give insight in how the delay will develop. The signal operator can use this information when identifying future conflicts and determining adequate interventions to resolve conflicts.

Secondly, the ability of ATO to automatically update the journey profile within the train allows signal operators to resolve conflicts by changing the arrival time without requiring voice communications with the train driver. However, it must be noted that this function requires additional capabilities from the traffic management system. Furthermore, driver advisory

[7] Track section between two station areas

system can also provide up to date timetable information to the train driver without voice communication between the signal operator and train driver.

Thirdly, the availability of speed and location information helps signal operators with their situation awareness. Having a more complete and accurate picture of the state of infrastructure and railway traffic helps the signal operator to prioritize actions. For example, when a train is stopped on an unexpected location, such as the open track, the signal operator can proactively contact the driver and determine the problem.

Limitations of ATO from the perspective of a signal operator

ATO is not a safety critical system. This results in some limitations to what functions can be performed by ATO, even though these functions might be possible from a technical perspective. These functions include temporary speed restrictions, automatically stopping trains during emergencies, or preventing trains from entering certain track sections. ATO can only perform operational functions, safety critical functions require a safety critical system.

Train drivers are the eyes and ears of the signal operator. The train driver informs the signal operator of people, animals, or objects along the track and irregularities resulting in shaking or weird noises. The signal operator uses this information to take appropriate actions such as informing other train drivers or ordering a track inspection. The ATO system considered in this report is of Grade of Automation 2, whereby a driver is present and can inform the signal operator of irregularities. However, this is not the case for GoA 3 or 4 systems, whereby these functions of the train driver should be taken over by sensors.

7.2.2 Case 1: Current Situation

The processes to retime the express train is discussed according to the developed SysML representations of the system described in chapter 6. The steps which are discussed below have been indicated in figure 42, the following steps have to be taken.

1. **Interlocking determines track occupation**
   The location of trains is determined by track occupation systems in the track. Track occupation information is read by the interlocking system.
2. **ASTRIS relays the track occupation to TROTS**
   The ASTRIS system relays track information to the TROTS system. ASTRIS functions as an interface between the ProRail traffic management systems and the interlocking.
3. **TROTS identifies track occupation as the location of the local train**
   Track occupation itself only indicates whether a track is free or occupied by a train. The TROTS system adds a train number to the track occupation measurement. This allows other systems to identify the location of a train.
4. **Procesleiding determines the delay of the local train**
   The procesleiding system is used by signal operators to receive information about the state of railway traffic and make interventions into railway traffic. The delay of a train is determined by the difference between the planned passing time and the actual passing time at a timetable point.
   The delay can be measured at timetable point Groningen (Gn), Vierverlaten (VVL), or Zuidhorn (Zh).
   The delay of the local train and the location of the delay measurement is indicated to the signal operator. Currently procesleiding does not make a prediction delays at later timetable points.
   The precise location of the local train is unknown to the signal operator when the train is located on the open track. There is no connection between the automatic block system and the ProRail traffic management system.

5. **The signal operator estimates a new passing time for Grijpskerk Aansluiting**
   The signal operator has to estimate the delay of the local train at the conflict point Grijpskerk Aansluiting. Other than the initially measured delay and the experience of the signal operator no tools are available to support the signal operator in the estimation.
   To allow the express train to reduce its speed and prevent an unplanned stop a new passing time must be set for Grijpskerk Aansluiting. This passing time must be estimated by signal operators. Whereby both the delay of the local train and the time to set a new route must be taken into account. Again no additional tools are currently available to support the signal operator in this task.
6. **The signal operator communicates the new passing time via GSM-R voice communication**
   No driver information system or driver advisory system is used on the railway line between Groningen and Leeuwarden. Therefore, a new passing point must be communicated to the train driver of the express train using GSM-R voice communication.
7. **The train driver estimates actions to be taken to achieve new passing point**
   The train driver of the express train must slow down the train such that the new passing point is reached in an optimal way. The train driver does not have tools available to support in this task other than previous experience.

Signal operators mention that the current process is not followed for minor disruptions to railway traffic. Several reasons are mentioned for this.

- No passing time prediction is available at timetable points such as Grijpskerk Aansluiting. A signal operator has only his experience and the measured delay at a previous timetable point at his disposal to estimate the passing time if a train is delayed.
- A signal operator is not supported in determining a new appropriate passing time for the express train at Grijpskerk Aansluiting.
- No DIS or DAS is available to support the communication between a signal operator and a train driver. The signal operator must call the train driver via GSM-R to inform the train driver about the new passing point. Calling the train driver for non-safety related issues is undesired because of the possibility of distracting the driver.
- The train driver is not aided in determining the right action given the new passing time. The train driver must estimate the speed based on experience.

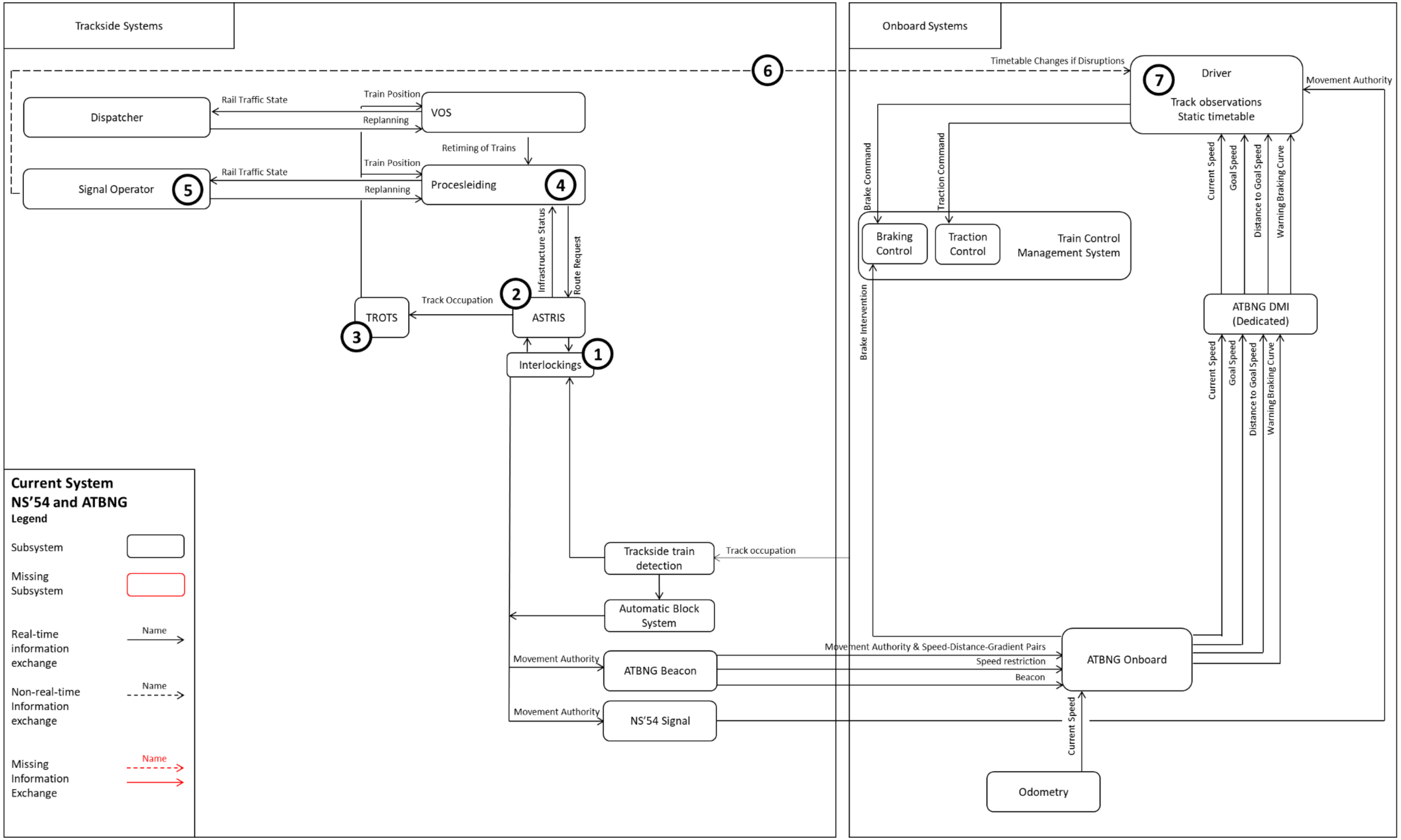


Figure 42 Retiming process in current situation

7.2.3 Case 1: ATO over ETCS

ATO over ETCS Grade of automation 2 system adds additional tools to support a retiming function. This changes the process. The new process is discussed according to the previously developed SysML representation of the system. The steps which are discussed below have been indicated in figure 43. In the ATO over ETCS the following steps have to be taken to retime the express train in response to a delayed local train.

1. **ETCS onboard determines distance passed since last balise**
   The ETCS onboard of the local train determines the distance passed since the last balise by reading out the odometry system.
2. **The ATO onboard determines the position of the train based on distance since last balise and balise location**
   The ATO onboard of the local train receives the distance passed and the location of the balise from the ETCS onboard. This set of information is used to determine the current position of the train.
3. **The ATO onboard uses the current position and train characteristics to predict the arrival time at future timing points**
   The ATO onboard of the local train predicts the arrival time at the Grijpskerk Aansluiting timing point. A timing point prediction is made using the current location and train characteristics.
   The timing point prediction and the current status of the train are sent to the ATO trackside.
4. **The ATO trackside relays the predicted future timing point to the ProRail Traffic Management System**
   The ATO trackside collects the current status and timing point predictions from all ATO onboards. The ATO trackside sends this information to the ProRail traffic management system.
   The number of future timing points for which a prediction is send to the ProRail traffic management system is as of yet undecided. A trade of must be made between reliability and providing the opportunity to intervene. Predicting too far in the future might initiate unnecessary interventions when delays reduce overtime. Predicting not far enough an potential opportunities to intervene might be missed.
5. **A new function of procesleiding, the ATO function, presents the delay of the local train to the signal operator**
   A new function of procesleiding presents the timing point prediction to the signal operator as a delay. Providing additional information for a signal operator to support the task of retiming a train.
6. **The signal operator determines a new passing time for the express train based on the predicted delay of the local train**
   The delay information allows the signal operator to determine a conflict is present and retime the express train to only pass Grijpskerk Aansluiting after the Local train has exited the single track section and a route has been set for the express train.
7. **The signal operator will use another new function of procesleiding to change journey profile of the express train**
   The journey profile of the express train must be changed to resolve the conflict between the express train and the local train.
8. **The ATO trackside sends the updated timing point to the ATO onboard as part of a journey profile update**
   The new timing point is sent from procesleiding to the ATO onboard as part of a journey profile update. This process is automatic and no voice communication is required between the signal operator and the train driver.

9. **The ATO onboard recalculates the speed profile and gives a new traction/braking command to the train**
   The ATO onboard can automatically recalculate an energy efficient speed profile reducing the speed of the train to prevent an unplanned stop. No estimation is required by the train driver.
10. **The ATO status changes to indicate a braking or coasting status to the driver**
   The ETCS DMI will update the status of ATO from accelerating/cruising/coasting to coasting/braking depending on the current action ATO is taking and the specific action required.

This case shows that ATO over ETCS can support the signal operators and the train driver in making and executing interventions in railway traffic.

Signal operators gain access to a more precise prediction of future arrival times. In this case this would eliminate the need for signal operators to estimate the arrival time of the local train at Grijpskerk Aansluiting. ATO by itself cannot predict at what time a route would be set for the express train. The signal operator would be responsible for estimating a time when the express train can pass Grijpskerk Aansluiting. Procesleiding uses standardized process times to determine the setup time based on the planned arrival/passing/departure time of the train. These times could be used to determine the new timing point of the express train.

ATO over ETCS allows a new timing point to be automatically sent to the train. Procesleiding sends the new timing point to the ATO trackside which relays it to the ATO onboard. It is no longer required to communicate a new timing point to the train driver using GSM-R voice communication.

Train drivers do not need to estimate the appropriate speed of the train to reach a timing point exactly at the specified time. The ATO system can calculate the appropriate speed profile required to reach the new timing point.

However, it is noticed that train drivers are not informed about an update to the Journey Profile. Subset-130 (UNISIG, 2018c) does not include a package of information which tells the ETCS DMI to display that a change has been made to the journey profile. In this specific case an express train would lower its speed ahead of the conflict to prevent making an unscheduled stop. Research in aviation shows that automation induced surprises such as sudden changes in speed or altitude can lead to pilots perceiving the actions of the automated system as failures, resulting in pilots trying to intervene inappropriately (Wickens, 2003). This case is similar, the action of the ATO system is counterintuitive. An express train is not expected to slow down during its run. It is logical in reaction to the delayed local train. However, this is not known to the train driver. The train driver can perceive the action as a failure and intervene by taking over control and accelerating the train back to the regular speed. However, the conflict with the local train is thereby not solved. Signals will order the train driver to stop the train and wait until after the local train has exited the single track section. Thus reducing the effectiveness of traffic management interventions made based on ATO information.

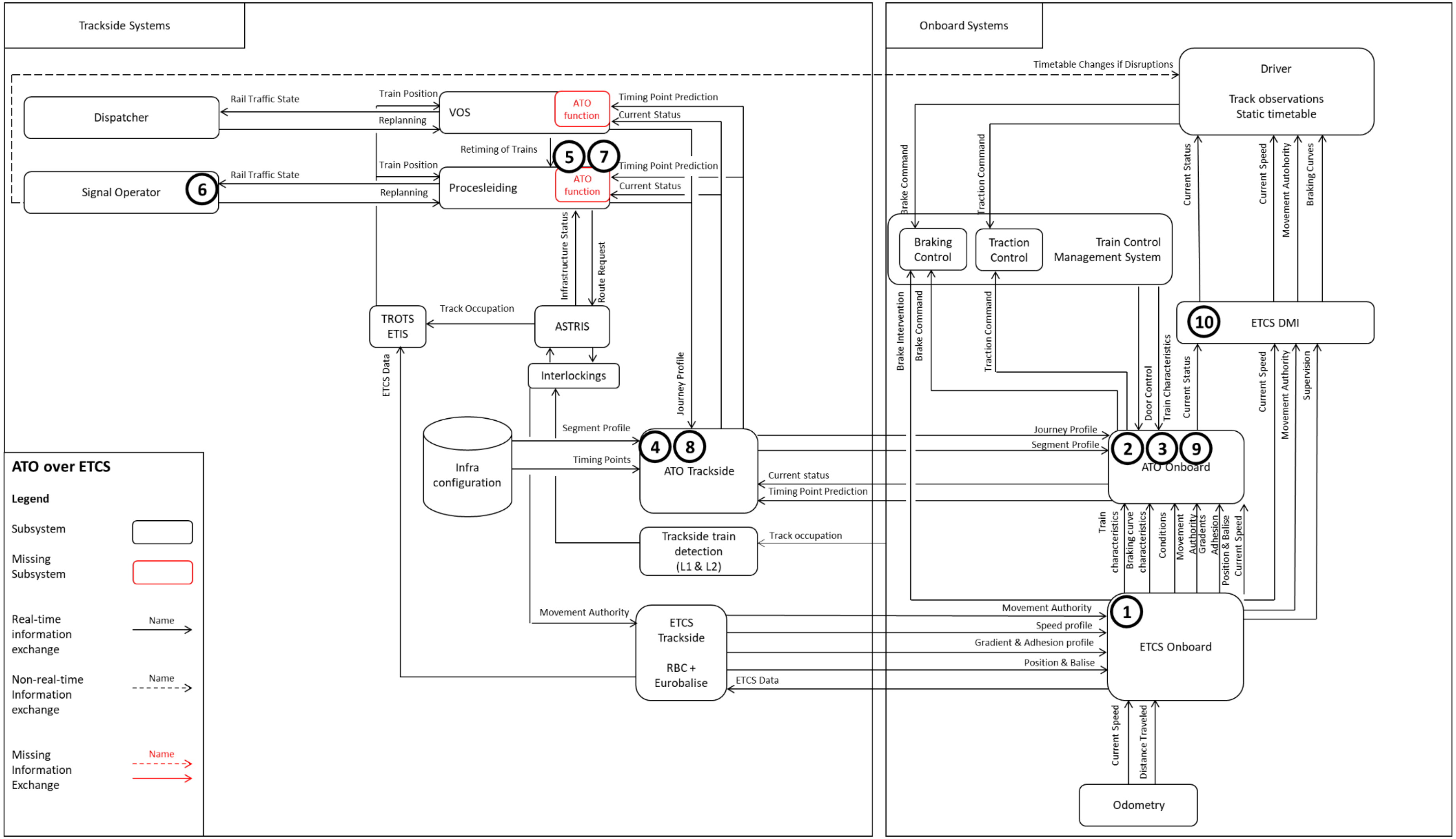


Figure 43 Retiming process with ATO over ETCS

7.2.4 Case 1: ATO over ATBNG

This section discusses the process under ATO over ATBNG Grade of Automation 2 system. The new process is discussed according to the previously developed SysML representation of the system. The steps which are discussed below have been indicated in figure 44. In ATO over ATBNG the following steps have to be taken to retime the express train in response to a delayed local train.

The analysis showed that a large number of steps taken for ATO over ATBNG are the same as with ATO over ETCS. Therefore, only the steps which differ from ATO over ETCS are discussed.

1. **The ATBNG onboard determines the distance passed since last passed beacon.**
   The ATBNG system determines the distance passed since the last balise based on information from the Odometry system.
2. **The ATO onboard determines the location of the train based on the beacon location and the distance passed since the last beacon.**
   The ATO onboard reads the distance passed since last beacon from the ATBNG onboard system using the ARR protocol. The signal location is known as it is included in the segment profile. Combining the information allows the ATO onboard to determine the position of the local train.
6. **The signal operator determines a new passing time for the express train based on the predicted delay of the local train**
   The delay information allows the signal operator to determine a conflict is present and retime the express train to only pass Grijpskerk Aansluiting after the Local train has exited the single track section and a route has been set for the express train. Furthermore, with ATO over ATBNG the signal operator can now determine the current location of the train in opentrack sections. Because ATO does not rely on the automatic block system to send its location to Procesleiding.
10. **The ATO status changes to indicate a braking or coasting status to the driver**
   The ATO DMI will update the status of ATO from accelerating/cruising/coasting to coasting/braking depending on the specific action required.

The ATO over ATBNG system determines its position differently. The ATO onboard must be capable of determining its position based on the distance passed since the last ATBNG beacon.

Furthermore, ATBNG is not equipped with a DMI capable of providing the train driver with ATO information. Thus the train driver is informed via a new DMI, the ATO DMI. This can be a simple screen displaying ATO information.

The intermediate steps dealing with the communication between ATO onboard and ATO trackside the same for ATO over ETCS and ATO over ATBNG. Solving the problems similarly.

- Signal operators are supported by the timing point prediction. Retiming is no longer solely based on measured delays at previous timetable points and the experience of signal operators.
- Communicating a new timing point to the train driver is automated by the ATO system. No voice communication is required between the signal operator and the train driver.

- ATO is capable of calculating the appropriate speed profile to achieve the new timing point. Determination of the appropriate speed profile to achieve the timing point is no longer only based on driver experience.

7.2.5 Case 1: Findings

The case describes an express train entering a single track section being hindered by a delayed local train causing a conflict. If the delay of the local train is more than three minutes, the express train will be hindered and must stop before the signal protecting this conflict point. This unplanned stop will result in additional energy consumption, a reduction in passenger comfort and potentially additional delay. Anticipating train control can mitigate the negative effects of an unplanned stop.

The current system of no ATO and ATBNG does not allow for anticipating train control which requires a retiming intervention, and the support by current tools is limited.

- A new timing point must be determined based on a previously measured delay and experience of the signal operator.
- The new timing point can only be communicated to the train driver via GSM-R voice communications.
- The train driver must estimate the appropriate speed profile

ATO over ETCS and ATO over ATBNG can provide additional tools to support both the signal operator and the train driver in implementing and executing a retiming order.

- The ATO system provides a timing point prediction indicating the arrival time at future timing points. Signal operator no longer have to estimate the delay.
- The ability to update the journey profile with a new timing point removes the need to communicate new timing points to the train driver using GSM-R voice communication. However, the update must be indicated to the train driver to prevent the train driver from intervening.
- The ATO system is capable of automatically optimizing its speed profile for the new timing point. The train driver no longer has to estimate the required speed profile based on the new timing point and his/hers experience.

This theoretical case indicates the potential of using timing point prediction information to support signal operators and train drivers in traffic management interventions. However, simulations could provide more insight to determine if the timing point prediction is sufficient to allow signal operators to estimate a new timing point.

Furthermore, it is shown that train drivers can be confronted with unexpected behaviour. A journey profile update including a new timing point is not indicated to a train driver. Simulations could provide insight to determine if train drivers would trust the ATO system when it slows down a train counterintuitively. Perhaps other sources of information could allow the train driver to determine if the behaviour of ATO is correct. One possibility is the introduction of Routelint in conjunction with ATO. This system allows train drivers to see track occupation. Based on track occupation a train driver could asses if the behaviour of ATO is correct. Or this can be mitigated by informing the train driver about the reason behind the behaviour. How this message should be presented from an ergonomic point of view should be investigated.

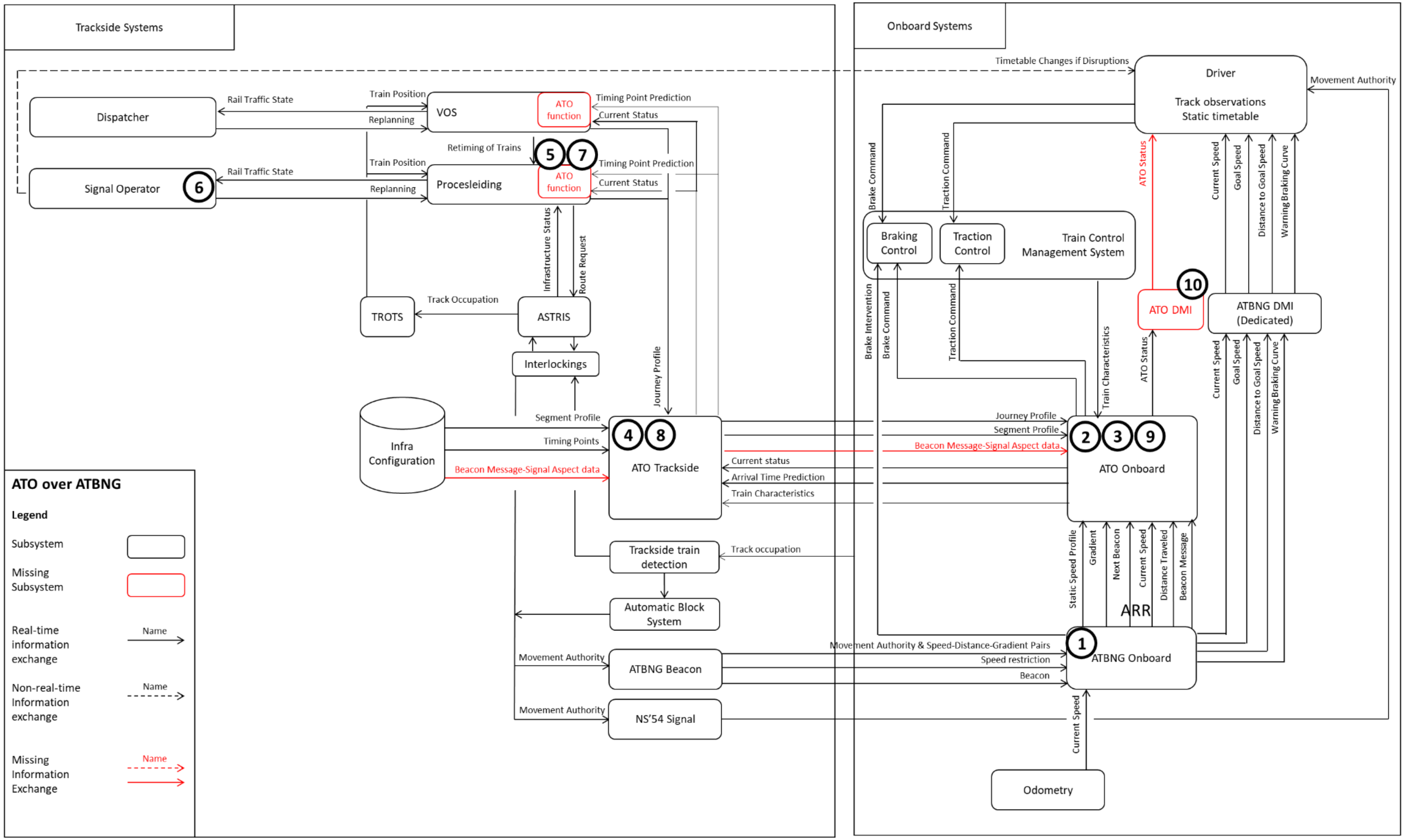


Figure 44 Retiming process with ATO over ATBNG

7.3 Case 2: Red signal approach

The analysis of ATBNG showed a difference between the NS'54 signalling operational envelope and the ATBNG operational envelope (braking according to signal aspects or ATBNG braking curve respectively). Therefore, the case of stopping in front of a red signal is worked out in more detail.

The first step is to determine the amount of time ATO over ATBNG needs to execute a braking action. The second step, presented in section 7.3.2 is to determine the amount of time available to ATO to execute the braking action. Section 7.3.3 tests the applicability of the minimal case by analysing a real world case. The findings of this case study are discussed in section 7.3.4.

Section 6.3.1 discusses different solutions for non-delayed braking. This chapter is written with solutions 2 and 3 in mind. These solutions allow the ATO onboard to determine the signal state based on the beacon message. Thus, signal states are updated at beacon locations.

The results can be interpreted both form the perspective of delayed and non-delayed braking. Section 7.3.5 gives a discussion on this topic.

7.3.1 ATO over ATBNG red signal approach process time

The red signal approach process can be derived from the ATO over ATBNG conceptual model. Figure 45 indicates the steps of the process, the steps are elaborated below.

1. **The ATO over ATBNG train reads an ATBNG beacon**
2. **The ATBNG onboard system processes the beacon message**
3. **The ATO onboard reads the beacon message via the ARR protocol**
4. **The ATO onboard process the ATBNG beacon message and determines a braking action**
5. **The braking system receives the braking message and applies the brake**
6. **Braking to stop**

The total ATO over ATBNG red signal approach process time is made up of the required time for each step. The assumptions made concerning the process time of each step are discussed below and summarized in table 4.

The time required by ATBNG to read the ATBNG beacon is assumed to be 0.02 seconds. This assumption is based on the length of the beacon and the maximum speed at which ATBNG can function (360 km/h). A beacon length of 2 meter (railpro, 2019) results in a read time of 0.02 seconds.

The time required by the ATBNG onboard to process the beacon message is unknown. A process time of one second is assumed.

A new message is available on the ARR protocol every one second. Therefore, if a new message is available just after a message is sent it will take one second to send that new message. Thus, process of ATO reading the ARR message is assumed to be one second.

It is unknown what the reaction time of the ATO onboard will be. Calculations made for High Speed 2 in the UK use an ATO reaction time of 3 seconds (McNaughton, 2011), therefore it is assumed that ATO can determine the braking action in 3 seconds. It is assumed that the additional time required because of asynchronous processes is included in the this reaction time.

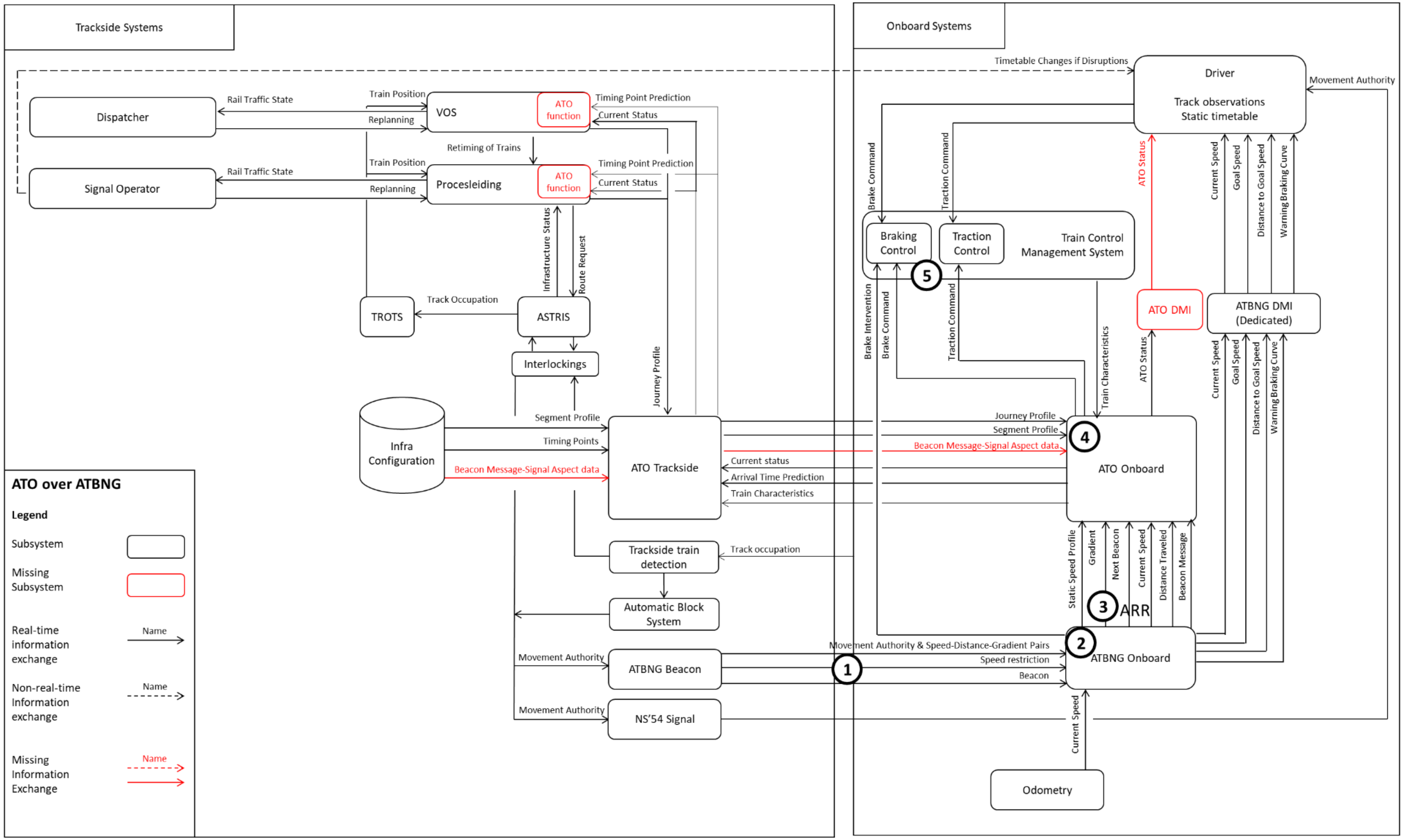


Figure 45 ATO over ATBNG red signal approach process.

Action		Process Time [s]
1.	**The ATO over ATBNG train reads an ATBNG beacon**	0.02
2.	**The ATBNG onboard system processes the beacon message**	1
3.	**The ATO onboard reads the beacon message via the ARR protocol**	1
4.	**The ATO onboard determines the braking action**	3
5.	**The braking system receives the braking message and applies the brake**	1.6
	Total	6.62

Table 2 Overview of assumed process times ATO over ATBNG and total ATO over ATBNG process time.

The process time between sending a brake command and the application of the brakes is the brake build-up time. A value of 1.6 seconds is used in a simulator developed for Groningen (Luipen, 2019). The simulator has been validated by train drivers. It is assumed that during the brake build-up time the brake force is zero.

The process in which ATBNG and ATO determine the brake action is assumed to take place at line speed. Table 3 presents the distance covered during the red signal approach process for different line speeds in column 2.

After the ATO over ATBNG system has determined the brake action the train must brake to a stop. The braking distance of the train is based on an assumed constant deceleration of -0.66 m/s^2. This is the service brake deceleration of the Arriva GTW trains running between Groningen and Leeuwarden. This number has been received from ProRail capacity management, which receives rolling stock data from Ricardo Rail. This braking distance is not the braking distance resulting from the ATBNG braking curve. However, in normal operation the emergency brake is not use to brake for a red signal. For different line speeds the service brake distance is calculated and presented in column 3 of table 4.

Line Speed [km/h]	Red signal approach process distance [m]	Service brake distance [m]	Total required distance [m]
140	258	1146	1404
120	221	842	1063
100	184	585	769
80	148	375	523

Table 3 Total distance required for red signal approach process and service brake process.

The sum of the red signal approach process and the service brake distance is the minimal distance before the red signal ATO over ATBNG must receive information regarding the signal state of the red signal in order to start braking in time to stop in before the red signal location.

7.3.2 Minimal distance available for ATO over ATBNG red signal approach process

Design guideline OVS69133 (ProRail, 2019c) states that the minimal distance between a main and distant signal is the gross braking distance. The gross braking distance is laid down in design guideline OVS69132 (ProRail, 2019d). The railway line between Groningen and Leeuwarden is equipped with ATBNG therefore no ATBEG supplements have to be added to the nett braking distance to determine the gross braking distance. A negative gradient of 5 ‰ is assumed in determining these values. The resulting minimal braking distances and therefore minimal signal distances for different line speeds are presented in column 2 of table 5. Column 3 presents the total required distance for the ATO over ATBNG red signal approach process (see also column 4 of table 3).

It must be noted that the presented minimal signal distance is the technical minimum. In practice signals can be placed further apart taking into account other factors such as: required minimal technical headways, sight distances, conflict point locations, etc. However, it is the critical distance at which the ATO over ATBNG system must be able to perform a stop before a red signal.

Line speed [km/h]	Minimal signal distance [m]	Total required distance [m]
140	1150	1404
120	1000	1063
100	1000	769
80	800	523

Table 4 Overview of distances covered during ATO over ATBNG process and braking process.

7.3.3 Red signal approach with minimal signal distances

Figure 46 presents a summary of both the distance required for the ATO over ATBNG process, including the service braking distance, and the minimal signal distances.

The figure should be interpreted as follows. Trains run from right to left. The minimal signal distance is the smallest distance between a red and yellow signal. The minimal signal distance depends stepwise on the line speed. Two minimal signal distances is the smallest distance between a red and a green signal.

The service brake distance gives for each speed the distance at which braking must start to ensure the train is stopped at the red signal. It is not a braking curve. The black line combines the ATO over ATBNG process distance and the service brake distance. It is the latest point before the red signal at which ATO must know the signal state of the red signal.

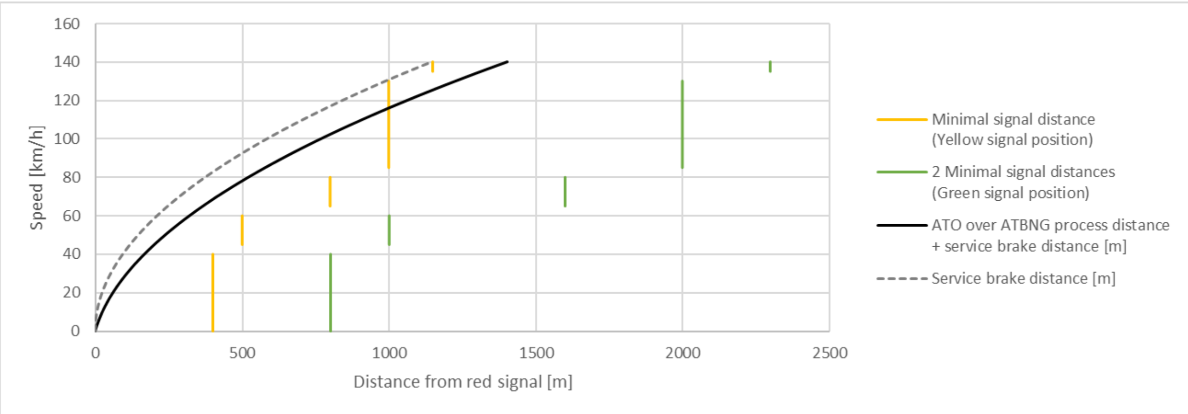


Figure 46 ATO over ATBNG process distance and minimal signal distances.

For line speeds of 80 and 100 km/h the minimal signal distance is longer than the required distance for the ATO over ATBNG red signal approach process. Figure 47 gives a visualization, the ATO over ATBNG red signal approach process fits within the difference between the service brake distance and the minimal signal distance. Therefore, the ATO over ATBNG system can act based on the message of the beacon at the yellow signal. However, only if delayed braking[8] is allowed. If non-delayed braking[9] is required then ATO must act on the last beacon before the yellow signal. Depending on non-delayed or delayed braking the braking starts at the yellow signal or at the service brake distance from the red signal. These points are indicated by arrow 1 and 2 respectively in figure 48. Sufficient time

[8] Braking according to the ATBNG operational envelope
[9] Braking according to the NS'54 operational envelope

is available for the ATO over ATBNG system to determine the signal aspect of the yellow signal and stop in front of the yellow signal.

Furthermore, for delayed braking the system will perform as required when the signal aspect improves. If the yellow aspect improves to a green aspect, ATO over ATBNG has sufficient time to process the new beacon message and determine a brake action is not required. For delayed braking an improved signal aspect can only be taken into account after the passage of the yellow signal.

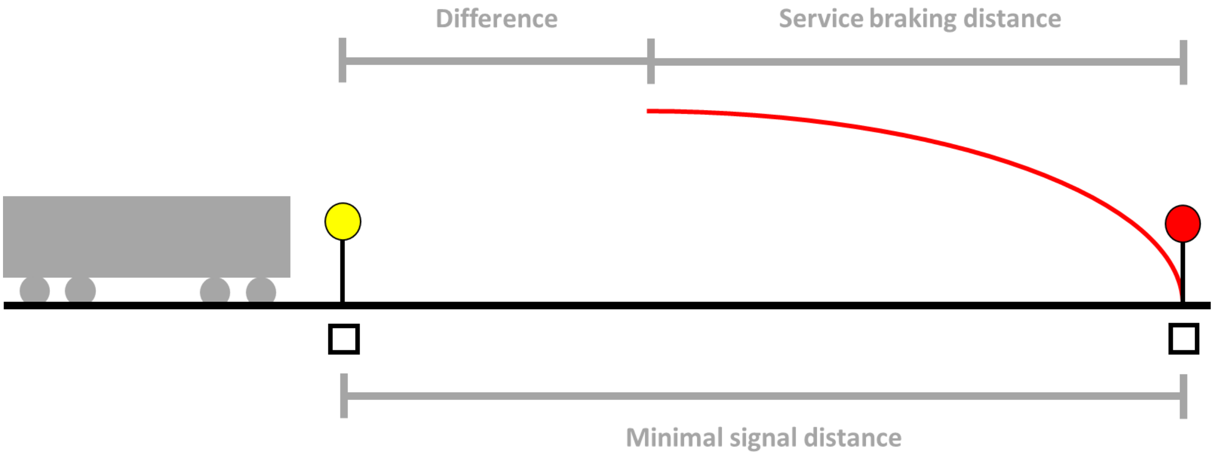


Figure 47 Difference between minimal signal distance and service brake distance

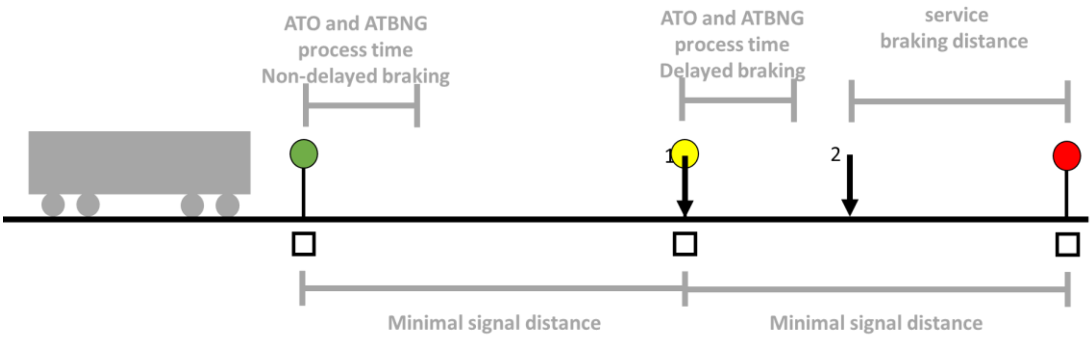


Figure 48 Braking process if ATO over ATBNG red signal approach process distance is shorter than minimal signal distance. 1: start braking point non-delayed braking. 2: start braking point delayed braking.

Figure 46 shows that for line speeds above about 115 km/h, thus line speeds of 120 and 140 km/h, the minimal signal distance is shorter than the required distance for the ATO over ATBNG red signal approach process. The ATO over ATBNG system must therefore act based on the message of the beacon at the green signal. This beacon message does contain a movement authority ending at the red signal (ProRail, 2018d). The total ATO over ATBNG process time is shorter than two minimal signal distances. Therefore sufficient time is available for the ATO over ATBNG red signal approach process.

However, from a performance point of view a potential issue arises. The process of ATO over ATBNG determining the signal aspect and applying the brakes must start before the passage of the yellow signal to ensure the train is stopped before the red signal, shown in figure 46. If the yellow signal aspect improves, ATO over ATBNG will already be in the process of applying the brakes. After the passage of the now green signal, ATO over

ATBNG must then go through the process of releasing the brakes. The result is that the train starts braking and then releases the brakes again. This behaviour is unwanted and limits performance.

Potential solutions are:

- **ATO approaches a yellow signal with a reduced speed**
  By reducing the speed when approaching a yellow signal the distance covered during the ATO over ATBNG process time and the service brake distance is reduced. Reducing the speed moves the point at which ATO must decide to apply the brakes closer to the red signal. If the speed is low enough the decision point is moved to after the passage of the yellow signal. Figure 46 shows that this speed is about 125 km/h for a 140 km/h line speed. This speed is determined by calculating at what speed the distance required by the ATO over ATBNG red signal approach process is equal or less ten the minimal signal distance. This is the case for 125 km/h which has a process distance of 1144 m which is less than the minimal signal distance of 1150 m for the 140 km/h line speed.
- **Add additional ATBNG beacons before signals**
  The addition of ATBNG beacons before signals allows the ATO over ATBNG system to receive a new movement authority sufficiently early.

It must be noted that the described case is the most critical case. In practice signal distances can be longer than the minimal required signal distances. Additional ATBNG beacons are already applied today to improve performance with manual operation.

7.3.4 Red signal approach with real world distances

The case described in the previous section concerns the most critical case with a minimal signal distance. As noted before this is a technical minimum, in practice signal distances are often longer. In this section a real world case is studied.

A minimal signal distance is applied on the track section between Groningen and Buitenpost according to the OBE-drawings (a list of valid drawings is given in appendix e The situation is presented in figure 49, the signal distances are indicated. Furthermore, beacon locations and the distance to the next signal are indicated.

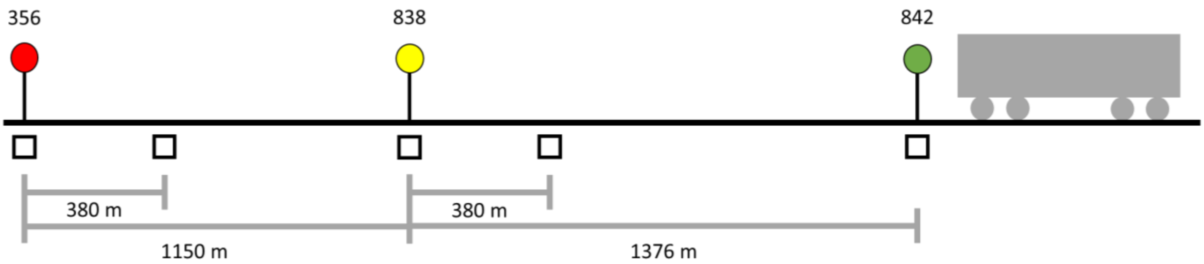


Figure 49 Signal distances from Groningen to Buitenpost, just before Buitenpost.

Figure 50 presents a red signal approach to signal 356. The grey dotted line shows the service braking curve assuming a braking rate of -0,66 m/s^2. The orange diamond indicates the location at which ATO over ATBNG can react on a new beacon message. Thus, it shows that the beacon message at the yellow signal cannot be taken into account without the braking process already having started. The vertical grey lines indicate additional beacons, the beacon message of the beacon just before signal 838 can be taken into account by the ATO over ATBNG system. Only if the signal aspect of signal 838 improves when the train is located between the beacon and signal 838 ATO over ATBNG cannot take into account the improved signal aspect.

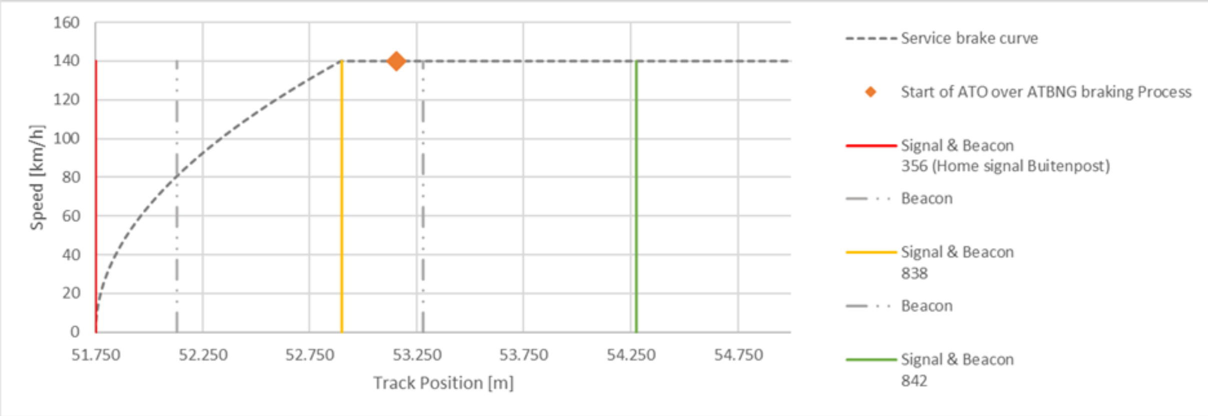


Figure 50 Red signal approach to signal 356, located at Buitenpost.

7.3.5 Findings: Case 2 red signal approach case.

The preliminary calculations made for the red signal approach case show that for line speeds of 80 and 100 km/h the minimal signal distance is sufficient to allow ATO to stop in front of the red signal, acting on the beacon message received at the yellow signal location. Thus, both from a safety and a performance perspective the ATO over ATBNG system has sufficient distance to stop in front of a red signal. Here the perspective of delayed braking is taken.

Furthermore, the preliminary calculations show that for line speeds of 120 and 140 km/h sufficient distance is available to stop in front of a red signal from a safety perspective. However, from a performance point of view insufficient distance is available.

Furthermore, if the perspective of non-delayed braking is taken ATO must always act based on the last beacon before the yellow signal location. Depending on the precise location of the beacon this might further impact performance.

Different solutions are possible such as the reduction of speed when the ATO train approaches a yellow signal or adding additional ATBNG beacons. The real world case study shows that additional beacons are already applied to improve the performance of manual operation.

The assumptions made for the calculations should be tested during the test runs to ensure the assumptions are correct. Furthermore, the case described takes into account the most critical case. The track section on which ATO over ATBNG is to be introduced should be checked to see if this critical case does indeed occur in practice. Microscopic simulations which take into account the location at which ATO over ATBNG receives information to determine braking behaviour can provide more insight in the performance aspect.

7.4 Case 3: Passing a level crossing

Collisions on level crossings are seen as a significant risk area in rail operations (UIC, 2018). Therefore, the case of passing a level crossing is discussed as well.

In the current situation it is the train driver who is responsible for observing level crossings are free from obstacles. Furthermore, not only level crossings are observed; in fact, a train driver constantly observes the track to ensure it is free of obstacles.

If an obstacle is detected a train driver will apply the brakes of the train. However, the braking distance of a train is generally longer that the sight distance of the train driver. Therefore, if braking is applied based on observing an obstacle this often cannot prevent a collision.

The SysML model shows that the ATO onboard does not receive information which would allow the system to determine if the level crossing is free or not.

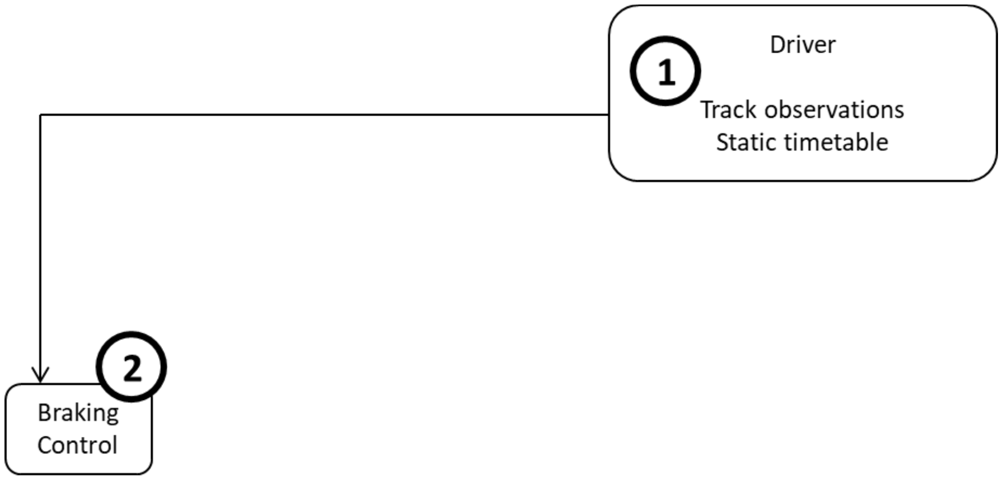


Figure 51 Tasks passing a level crossing case.

Grade of automation 2 systems rely on the train driver to observe the track and to intervene in the case of obstacles. The following steps are taken in the approach of a level crossing. The numbers correspond with the numbers indicated in figure 51.

1. **Train driver observes the track and level crossings for obstacles**
2. **If an obstacle is present the train driver applies the brake**

Thus, it is the train driver who is responsible for observing level crossings and intervening by applying the brakes whenever an obstacle is present on the level crossing. The ATO system does not provide support to the train driver while approaching a level crossing.

The responsibility is the same as in the current system. However, it must be noted that the context of task changes. In the current situation observing the track is executed within an active driving context. With ATO over ATBNG Grade of Automation 2 the task is executed in an observation context.

Endsley and Kiris (1995) state “evidence suggests that passive processing of information may be inferior to active processing”. Response times of train drivers might increase if a task is part of the more passive observation context. However, research specifically into the topic of the Out-of-the-loop problem in railway is limited. Therefore, additional research into the out-of-the-loop problem in the context of a level crossing approach is recommended.

ATO over ETCS requires driver to acknowledge unprotected level crossings (ERTMS Users Group, 2017b). This could be expanded to protected level crossings as well. Furthermore, this requirement should be made for ATO over ATBNG as well.

8. Conclusion and Recommendations

This chapter presents the conclusions and recommendations resulting from this report. The conclusions are presented in section 8.1. Recommendations are presented in section 8.2.

8.1 Conclusions

This section presents the conclusions of this report. The research questions presented in chapter 1 are answered separately.

The research has been carried out in three main steps. The first step is the development of a generic ATO model. In the second step the generic ATO model is used to analyse the ATO over ETCS and ATO over ATBNG systems. The result is a description of the functions of the subsystems and information exchange between the subsystems. The model has been validated by three case studies, these case studies include a traffic management case, a red signal approach case, and a level crossing case. The following conclusions can be drawn:

Scientific contributions

This research shows that SysML conceptual models can be used to analyse requirements for ATO systems over different signalling/automatic train protection systems.

The generic ATO model presented in chapter 4 can provide a framework to analyse other automatic train protection systems.

This master thesis report draws from the envelope of safe operation model by Van den Top (2010). The set of envelopes defined within the model help to identify the relevant envelope to be used by ATO. Furthermore, the model provides insight in the balancing between safety and operational performance.

What functions are expected from the GoA 2 system/Traffic Management System?

The generic ATO model defines three functions for the ATO system:

1. The ATO system must be capable of generating a trajectory based on the safety envelope, the train path envelope, route characteristics, and train characteristics.
2. The generated trajectory must be tracked against the actual trajectory to determine the required deceleration or acceleration.
3. The ATO system must be capable of determining the traction or braking command required to achieve the determined acceleration or deceleration.

Furthermore, the ATO over ATBNG Grade of Automation 2 system shall be capable of performing the same functions as ATO over ETCS. However, ATO over ATBNG does not necessarily perform the functions in the same way as ATO over ETCS does. ATO over ATBNG shall:

- Automatically drive a train from a stopping point to another stopping point
- Automatically stop at a predefined stopping point
- React on braking inputs from the train driver by disengaging and applying the brakes
- Remain engaged while passing a level crossing
- Be able to operate several coupled units as a single train
- Provide a DAS function when ATO GoA 2 is not engaged

What information is required for a GoA 2 system, both from track to train and vice versa?

The generic model presents the information which is required for an ATO Grade of Automation 2 system. The ATO system requires five sets of information to execute its function.

1. First of all the **safety envelope** is required. The safety envelope consists of a movement authority, a static speed profile, and starting conditions. The movement authority authorizes the train to proceed according to a safe and set route. The static speed profile describes the maximum speed along this route. The starting conditions indicate that all conditions for the safe activation of ATO are fulfilled.
2. Second, the **timetable** is required. The timetable of the train is described by the journey profile. The journey profile sets arrival/passing times for the timing points defined in the segment profile. Furthermore, the route of the train is specified by listing the segment profiles the train will traverse.
3. Third, **route characteristics** are required. The exact route is described by the segment profiles. Route characteristics are used by the ATO system to accurately model the driving behaviour and determine the correct traction and brake application. Route characteristics include: gradient profile, adhesion profile, curve profile, traction system, and stopping points.
4. Fourth, **train characteristics** are required to model driving behaviour and determine the correct stopping point. The train characteristics consists of traction characteristics, braking characteristics, resistance characteristics, and train length.
5. Fifth and last the **current status of the train** is required to be known for the ATO system. The current status feeds the feedback loop which tracks the actual trajectory against the generated trajectory. The current status consists of current speed, position, and the traction/brake position.

The ATO system provides three sets of information to surrounding systems:

4. First the **current status** of the ATO train. The current status includes the current speed, position and operational status of the ATO train.
5. Secondly the **timing point prediction**. The timing point prediction contains the predicted arrival/passing time at upcoming timing point locations. Furthermore, the type of timing point is indicated, this can be a stopping point or a passing point.
6. Thirdly **control commands**. In order for ATO to actually drive the train control commands must be sent to the braking system and the traction system.

Is the combination of the current traffic management system of ProRail and ATBNG equipped to deliver the required information for the ATO GoA 2 system?

- o *What information can ATBNG deliver?*
- o *What information should the ProRail traffic management system deliver?*

The ProRail traffic management system must deliver a journey profile and segment profiles to the ATO onboard.

- The journey profile is a description of the timetable.
- The segment profile is a description of the infrastructure

The ProRail traffic management system is currently not equipped to deliver journey and segment profiles to the train. The journey profiles should be updated and automatically sent to the ATO onboard based on interventions made by signal operators.

ATBNG is equipped to deliver the required information to the ATO onboard system. The ARR protocol can be used to provide the ATO system with ATBNG information.

The ATBNG onboard system is capable of delivering the safety envelope to the ATO onboard. However, only if the safety envelope is made up of the operational envelope of ATBNG, that is if the ATO brakes according to the ATBNG braking curve. If it is required that ATO brakes according to the NS'54 operational envelope additional information is required, that is ATO brakes according to the orders given by NS'54 signals and speed reduction signs. Additional information must supplement ATBNG information to allow the ATO onboard system to determine signal aspects of specific signals. Either by linking specific ATBNG beacon messages to specific signal aspects or by providing signal and sign locations.

Therefore, ATBNG information must be supplemented with signal location information or a database linking the beacon to a specific signal aspect to support non-delayed braking. Besides adding functionality to the ProRail TMS which allows journey and segment profiles to be deliverd to the train the aforementioned information must also be provided. Specifically, no database is present linking the ATBNG beacon message to the signal aspect, information currently in the PDL diagrams[10] should be added to the infrastructure configuration[11].

Furthermore, ATBNG is capable of delivering some train characteristics. These include train length and number of isolated brakes. Traction, resistance, and braking characteristics cannot be delivered by the ATBNG onboard. These characteristics either have to be preloaded into the ATO onboard or be delivered by the Train Control Management System.

Is the current traffic management system capable of utilizing the information provided by the ATO GoA 2 system to support real-time traffic management?

The current system is not capable of utilizing the information provided by the ATO GoA 2 system.

However, interviews with signal operators show that the information provided by the ATO system can support signal operators. The availability of a timing point prediction (a predicted arrival time at upcoming timing points) supports signal operators in determining the delay of a train. Currently, the delay is measured, signal operators must estimate the delay at the point of conflict. Furthermore, ATO could allow for automatic updates of the journey profile. Currently, changes to the timetable must be communicated to the train driver using GSM-R.

Modifications to the ProRail traffic management system are required. The information provided by the ATO system including current location, speed, and the timing point prediction must be presented to signal operators.

Which concrete steps can be taken towards connecting a future Automatic Train Operation with the Traffic Management System, for Arriva trains on Groningen - Buitenpost?

ATO over ATBNG connected to a traffic management system requires a number of steps to be taken and some challenges to overcome.

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[10] PDL-diagrams are part of the signalling file and contain beacon messages and the corresponding signal aspect.
[11] The infrastructure configuration is a database in which the track characteristics are stored.

The ATO over ATBNG conceptual model shows a number of new systems and modifications to the current systems.

The ATO trackside and ATO onboard systems must be added to the railway control system. The ATO onboard must be capable of determining a trajectory based on the timetable and the ATBNG/NS'54 operational envelope.

The ProRail traffic management system must be modified by adding a new component and new functions to Procesleiding and VOS to provide the information for the ATO system. The ProRail traffic management system must be modified to enable it to deliver a journey profile, segment profiles, and ATBNG information to the ATO trackside. Segment profiles must be expanded with NS'54 signal and speed sign locations. Furthermore, to allow ATO to determine the signal aspect information linking the ATBNG beacon message and the signal aspect must be delivered.

To use the information delivered from the ATO onboard system to the ProRail traffic management system for traffic management purposes a new function must be added to the ProRail traffic management system. This function must be capable of presenting the current status and timing point prediction information to the signal operator and dispatcher.

8.2 Recommendations

This section presents the recommendations for ProRail and for future research to support the implementation of ATO.

ATO over ATBNG can use many of the concepts developed for ATO over ETCS. Such as the journey profile and segment profile model to deliver timetable and route characteristics to the train. The work required to make the ProRail traffic management system capable of delivering the journey and segment profiles can be used by ATO over ATBNG as well. However, the data gap identified between ATBNG and ETCS requires additional information from the traffic management system. This information consists of signal and speed sign locations, and information linking the beacon message to the signal aspect can be delivered within the framework of the segment profile as they are track characteristics.

However, this study does not determine the investment cost. Additional studies determining the cost associated with the capability of delivering the additional information required for ATO over ATBNG are recommended.

The traffic management case study indicates that information provided by the ATO system can support signal operators with real time traffic management. However, additional research is recommended. The conclusions drawn in this report are based on a small number of interviews. These conclusions can be verified by using, for example, simulator studies. By modifying a simulator such that the information provided by the ATO system is presented inside the simulator it can be tested if the information does indeed support the task of the signal operator.

Furthermore, the train driver will receive additional information. An analysis should be performed to determine what the precise information need of the train driver is. The traffic management case shows that train drivers receive insufficient information to determine if ATO is taking the correct action. Additional information indicating a change to the journey profile might provide the additional required information.

The red signal approach case study shows that ATO over ATBNG receives information on red signals sufficiently early to allow ATO to safely stop before a red signal with a minimal signal distance. However, for minimal signal distances and line speeds above 115 km/h the process of braking starts before the passage of a yellow signal. If the signal aspect would turn to green just before the yellow signal is passed ATO over ATBNG must stop braking and accelerate again to line speed. It is recommended that ATBNG railway lines are analysed before ATO over ATBNG is rolled out. Potential solutions are the implementation of intermediate beacons just before the signal or implementing a lower yellow signal approach speed which would starting the process of braking just after the passage of the signal. Furthermore, the precise implications on either delayed or non-delayed braking should be identified.

The level crossing approach case shows that ATO changes the context of the tasks performed by the train driver. Currently, tasks of the train driver are part of an active driving context. Under automatic train operation GoA 2 the task of a train driver becomes part of a passive observation context. Research suggest that within an observation or passive context response times of operators might increase. However, research specific into the out of the loop topic is limited for railways. Further, research specific for railways is recommended.

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Appendix A Allocation of variables Subset-026 to categories

Packet		Variable Name	Remark	Category
		From trainside to trackside		
Position Report	0	NID_PACKET		Position
	0	L_PACKET		Position
	0	Q_SCALE		Position
	0	NID_LRBG		Position
	0	D_LRBG		Position
	0	Q_DIRLRBG		Position
	0	Q_DLRBG		Position
	0	L_DOUBTOVER		Position
	0	L_DOUBTUNDER		Position
	0	Q_LENGTH		Position
	0	L_TRAININT	If Q_LENGTH = “Train integrity confirmed by integrity	Position
	0	V_TRAIN		Position
	0	Q_DIRTRAIN		Position
	0	M_MODE		Position
	0	M_LEVEL		Position
	0	NID_NTC	If M_LEVEL = NTC	Position
Position Report based on two balise groups	1	NID_PACKET		Position
	1	L_PACKET		Position
	1	Q_SCALE		Position
	1	NID_LRBG		Position
	1	NID_PRVLRBG	Used as reference for all directional information in th	Position
	1	D_LRBG		Position
	1	Q_DIRLRBG	Train orientation according to reference direction	Position
	1	Q_DLRBG	Train front position according to reference direction	Position
	1	L_DOUBTOVER		Position
	1	L_DOUBTUNDER		Position
	1	Q_LENGTH		Position
	1	L_TRAININT	If Q_LENGTH = “Train integrity confirmed by integrity	Position
	1	V_TRAIN		Position
	1	Q_DIRTRAIN	Actual running direction according to reference direct	Position
	1	M_MODE		Position
	1	M_LEVEL		Position
	1	NID_NTC	If M_LEVEL = NTC	Position
Onboard supported system versions	2	NID_PACKET		Train characteristics
	2	L_PACKET		Train characteristics
	2	M_VERSION		Train characteristics
	2	N_ITER		Train characteristics
	2	M_VERSION (k)		Train characteristics
Error reporting	4	NID_PACKET		ETCS error
	4	L_PACKET		ETCS error
	4	M_ERROR	error type identifier	ETCS error
Train running number	5	NID_PACKET		Train characteristics
	5	L_PACKET		Train characteristics
	5	NID_OPERATIONAL		Train characteristics
Level 2/3 transition information	9	NID_PACKET		ETCS transition
	9	L_PACKET		ETCS transition
	9	NID_LTRBG		ETCS transition
Validated train data	11	NID_PACKET		Train characteristics
	11	L_PACKET		Train characteristics
	11	NC_CDTRAIN	Cant deficiency category of train	Train characteristics
	11	NC_TRAIN		Train characteristics
	11	L_TRAIN	lenght of train	Train characteristics
	11	V_MAXTRAIN	maximum speed of train	Train characteristics
	11	M_LOADINGGAUGE	loadinggauge of train	Train characteristics
	11	M_AXLELOADCAT	axleload category of train	Train characteristics
	11	M_AIRTIGHT	presence of airtightness system	Train characteristics
	11	N_AXLE	axle number of engine	Train characteristics
	11	N_ITER		Train characteristics
	11	M_VOLTAGE(k)	Identity of the traction system NID_CTRACTION(k)	Train characteristics
	11	NID_CTRACTION(k)	given only if M_VOLTAGE(k) ≠ 0	Train characteristics
	11	N_ITER		Train characteristics
	11	NID_NTC(k)	Type of National System available	Train characteristics
Data used by applications outside the	44	NID_PACKET		Packet 44
	44	L_PACKET		Packet 44
	44	NID_XUSER		Packet 44
	44	Other data, depending on NID_XUSER		Packet 44

From trackside to trainside				
Packet		Variable Name	Remark	Category
Virtual balise cover marker	0	NID_PACKET	Indication to on-board that the telegram can be ignored according to a VBC	
	0	NID_VBCMK		
System version number	2	NID_PACKET	This packet is used to tell the on-board which is the o	Track characteristics
	2	Q_DIR		Track characteristics
	2	L_PACKET		Track characteristics
	2	M_VERSION		Track characteristics
National values	3	NID_PACKET	Downloads a set of National Values to the train	ETCS national values
	3	Q_DIR		ETCS national values
	3	L_PACKET		ETCS national values
	3	Q_SCALE		ETCS national values
	3	D_VALIDNV		ETCS national values
	3	NID_C		ETCS national values
	3	N_ITER		ETCS national values
	3	NID_C(k)		ETCS national values
	3	V_NVSHUNT		ETCS national values
	3	V_NVSTFF		ETCS national values
	3	V_NVONSIGHT		ETCS national values
	3	V_NVLIMSUPERV		ETCS national values
	3	V_NVUNFIT		ETCS national values
	3	V_NVREL		ETCS national values
	3	D_NVROLL		ETCS national values
	3	Q_NVSBTSMPERM		ETCS national values
	3	Q_NVEMRRLS		ETCS national values
	3	Q_NVGUIPERM		ETCS national values
	3	Q_NVSBFBPERM		ETCS national values
	3	Q_NVINHSMICPERM		ETCS national values
	3	V_NVALLOWOVTRP		ETCS national values
	3	V_NVSUPOVTRP		ETCS national values
	3	D_NVOVTRP		ETCS national values
	3	T_NVOVTRP		ETCS national values
	3	D_NVPOTRP		ETCS national values
	3	M_NVCONTACT		ETCS national values
	3	T_NVCONTACT		ETCS national values
	3	M_NVDERUN		ETCS national values
	3	D_NVSTFF		ETCS national values
	3	Q_NVDRIVER_ADHES		ETCS national values
	3	A_NVMAXREDADH1		ETCS national values
	3	A_NVMAXREDADH2		ETCS national values
	3	A_NVMAXREDADH3		ETCS national values
	3	Q_NVLOCACC		ETCS national values
	3	M_NVAVADH		ETCS national values
	3	M_NVEBCL		ETCS national values
	3	Q_NVKINT		ETCS national values
	3	Q_NVKVINTSET		ETCS national values
	3	A_NVP12		ETCS national values
	3	A_NVP23		ETCS national values
	3	V_NVKVINT		ETCS national values
	3	M_NVKVINT		ETCS national values
	3	M_NVKVINT		ETCS national values
	3	N_ITER		ETCS national values
	3	V_NVKVINT(n)		ETCS national values
	3	M_NVKVINT(n)		ETCS national values
	3	M_NVKVINT(n)		ETCS national values
	3	N_ITER		ETCS national values
	3	Q_NVKVINTSET(k)		ETCS national values
	3	A_NVP12(k)		ETCS national values
	3	A_NVP23(k)		ETCS national values
	3	V_NVKVINT(k)		ETCS national values
	3	M_NVKVINT(k)		ETCS national values
	3	M_NVKVINT(k)		ETCS national values
	3	N_ITER(k)		ETCS national values
	3	V_NVKVINT(k,m)		ETCS national values
	3	M_NVKVINT(k,m)		ETCS national values
	3	M_NVKVINT(k,m)		ETCS national values
	3	L_NVKRINT		ETCS national values
	3	M_NVKRINT		ETCS national values
	3	N_ITER		ETCS national values
	3	L_NVKRINT(l)		ETCS national values
	3	M_NVKRINT(l)		ETCS national values
	3	M_NVKTINT		ETCS national values
Linking	5	NID_PACKET		Linking information
	5	Q_DIR		Linking information
	5	L_PACKET		Linking information
	5	Q_SCALE		Linking information
	5	D_LINK		Linking information
	5	Q_NEWCOUNTRY		Linking information
	5	NID_C		Linking information
	5	NID_BG		Linking information
	5	Q_LINKORIENTATION		Linking information
	5	Q_LINKREACTION		Linking information
	5	Q_LOCACC		Linking information
	5	N_ITER		Linking information
	5	D_LINK (k)		Linking information
	5	Q_NEWCOUNTRY(k)		Linking information
	5	NID_C (k)		Linking information
	5	NID_BG (k)		Linking information
	5	Q_LINKORIENTATION (k)		Linking information
	5	Q_LINKREACTION (k)		Linking information
	5	Q_LOCACC (k)		Linking information

virtual balise cover order	6 NID_PACKET	packat sets/removes a virtual balise cover	balise cover
	6 Q_DIR		balise cover
	6 L_PACKET		balise cover
	6 Q_VBCO		balise cover
	6 NID_VBCMK		balise cover
	6 NID_C		balise cover
	6 T_VBC		balise cover
Level 1 movement authority	12 NID_PACKET		Movement authority
	12 Q_DIR		Movement authority
	12 L_PACKET		Movement authority
	12 Q_SCALE		Movement authority
	12 V_MAIN		Movement authority
	12 V_EMA		Movement authority
	12 T_EMA		Movement authority
	12 N_ITER		Movement authority
	12 L_SECTION(k)		Movement authority
	12 Q_SECTIONTIMER(k)		Movement authority
	12 T_SECTIONTIMER(k)		Movement authority
	12 D_SECTIONTIMERSTOPLOC(k)		Movement authority
	12 L_ENDSECTION		Movement authority
	12 Q_SECTIONTIMER		Movement authority
	12 T_SECTIONTIMER		Movement authority
	12 D_SECTIONTIMERSTOPLOC		Movement authority
	12 Q_ENDTIMER		Movement authority
	12 T_ENDTIMER		Movement authority
	12 D_ENDTIMERSTARTLOC		Movement authority
	12 Q_DANGERPOINT		Movement authority
	12 D_DP		Movement authority
	12 V_RELEASEDP		Movement authority
	12 Q_OVERLAP		Movement authority
	12 D_STARTOL		Movement authority
Staff responsible	13 NID_PACKET		Movement authority
	13 NID_PACKET		Movement authority
	13 Q_DIR		Movement authority
	13 L_PACKET		Movement authority
	13 Q_SCALE		Movement authority
	13 Q_NEWCOUNTRY		Movement authority
	13 NID_C		Movement authority
	13 NID_BG		Movement authority
	13 Q_NEWCOUNTRY		Movement authority
	13 NID_C		Movement authority
	13 NID_BG		Movement authority
	13 D_SR		Movement authority
	13 N_ITER		Movement authority
	13 Q_NEWCOUNTRY (k)		Movement authority
	13 NID_C (k)		Movement authority
	13 NID_BG (k)		Movement authority
	13 D_SR (k)		Movement authority
Level 2/3 movment authority	15 NID_PACKET		Movement authority
	15 Q_DIR		Movement authority
	15 L_PACKET		Movement authority
	15 Q_SCALE		Movement authority
	15 V_EMA		Movement authority
	15 T_EMA		Movement authority
	15 N_ITER		Movement authority
	15 L_SECTION(k)		Movement authority
	15 Q_SECTIONTIMER(k)		Movement authority
	15 T_SECTIONTIMER(k)		Movement authority
	15 D_SECTIONTIMERSTOPLOC(k)		Movement authority
	15 L_ENDSECTION		Movement authority
	15 Q_SECTIONTIMER		Movement authority
	15 T_SECTIONTIMER		Movement authority
	15 D_SECTIONTIMERSTOPLOC		Movement authority
	15 Q_ENDTIMER		Movement authority
	15 T_ENDTIMER		Movement authority
	15 D_ENDTIMERSTARTLOC		Movement authority
	15 Q_DANGERPOINT		Movement authority
	15 D_DP		Movement authority
	15 V_RELEASEDP		Movement authority
	15 Q_OVERLAP		Movement authority
	15 D_STARTOL		Movement authority
	15 T_OL		Movement authority
	15 D_OL		Movement authority
	15 V_RELEASEOL		Movement authority
Reposition information	16 NID_PACKET		Movement authority
	16 Q_DIR		Movement authority
	16 L_PACKET		Movement authority
	16 Q_SCALE		Movement authority
	16 L_SECTION		Movement authority
Gradient profile	21 NID_PACKET		Gradients
	21 Q_DIR		Gradients
	21 L_PACKET		Gradients
	21 Q_SCALE		Gradients
	21 D_GRADIENT		Gradients
	21 Q_GDIR		Gradients
	21 G_A		Gradients
	21 N_ITER		Gradients
	21 D_GRADIENT(k)		Gradients
	21 Q_GDIR(k)		Gradients
	21 G_A(k)		Gradients

International Static speed proflie	27	NID_PACKET		Static speed profile
	27	Q_DIR		Static speed profile
	27	L_PACKET		Static speed profile
	27	Q_SCALE		Static speed profile
	27	D_STATIC		Static speed profile
	27	V_STATIC		Static speed profile
	27	Q_FRONT		Static speed profile
	27	N_ITER		Static speed profile
	27	Q_DIFF(n)		Static speed profile
	27	NC_CDDIFF(n)		Static speed profile
	27	NC_DIFF(n)		Static speed profile
	27	V_DIFF(n)		Static speed profile
	27	N_ITER		Static speed profile
	27	D_STATIC(k)		Static speed profile
	27	V_STATIC(k)		Static speed profile
	27	Q_FRONT(k)		Static speed profile
	27	N_ITER(k)		Static speed profile
	27	Q_DIFF(k,m)		Static speed profile
	27	NC_CDDIFF(k,m)		Static speed profile
	27	NC_DIFF(k,m)		Static speed profile
	27	V_DIFF(k,m)		Static speed profile
Track condition change of traction syst	39	NID_PACKET		Electrification system
	39	Q_DIR		Electrification system
	39	L_PACKET		Electrification system
	39	Q_SCALE		Electrification system
	39	D_TRACTION		Electrification system
	39	M_VOLTAGE		Electrification system
	39	NID_CTRACTION		Electrification system
Track condition change of allowed cur	40	NID_PACKET		Electrification system
	40	Q_DIR		Electrification system
	40	L_PACKET		Electrification system
	40	Q_SCALE		Electrification system
	40	D_CURRENT		Electrification system
	40	M_CURRENT		Electrification system
Level transition order	41	NID_PACKET	Packet to identify where a level transition shall take p	Movement authority
	41	Q_DIR		Movement authority
	41	L_PACKET		Movement authority
	41	Q_SCALE		Movement authority
	41	D_LEVELTR		Movement authority
	41	M_LEVELTR		Movement authority
	41	NID_NTC		Movement authority
	41	L_ACKLEVELTR		Movement authority
	41	N_ITER		Movement authority
	41	M_LEVELTR(k)		Movement authority
	41	NID_NTC(k)		Movement authority
	41	L_ACKLEVELTR(k)		Movement authority
Session management	42	NID_PACKET	Packet to give the identity and telephone number of	Session management
	42	Q_DIR		Session management
	42	L_PACKET		Session management
	42	Q_RBC		Session management
	42	NID_C		Session management
	42	NID_RBC		Session management
	42	NID_RADIO		Session management
	42	Q_SLEEPSESSION		Session management
data used by applications outside the	44	NID_PACKET		Packet 44
	44	Q_DIR		Packet 44
	44	L_PACKET		Packet 44
	44	NID_XUSER		Packet 44
	44	NID_NTC		Packet 44
	44	Other data, depending on NID_XUSER		Packet 44
Radio Network registration	45	NID_PACKET	Packet to give the identity of the Radio Network to w	Session management
	45	Q_DIR		Session management
	45	L_PACKET		Session management
	45	NID_MN		Session management
Conditional level transition order	46	NID_PACKET		Movement authority
	46	Q_DIR		Movement authority
	46	L_PACKET		Movement authority
	46	M_LEVELTR		Movement authority
	46	NID_NTC		Movement authority
	46	N_ITER		Movement authority
	46	M_LEVELTR(k)		Movement authority
	46	NID_NTC(k)		Movement authority
List of balises for sh area	49	NID_PACKET	Used to list balise group(s) which the train can pass o	Movement authority
	49	Q_DIR		Movement authority
	49	L_PACKET		Movement authority
	49	N_ITER		Movement authority
	49	Q_NEWCOUNTRY(k)		Movement authority
	49	NID_C(k)		Movement authority
	49	NID_BG(k)		Movement authority

Axle load speed profile	51	NID_PACKET		Static speed profile
	51	Q_DIR		Static speed profile
	51	L_PACKET		Static speed profile
	51	Q_SCALE		Static speed profile
	51	Q_TRACKINIT		Static speed profile
	51	D_TRACKINIT		Static speed profile
	51	D_AXLELOAD		Static speed profile
	51	L_AXLELOAD		Static speed profile
	51	Q_FRONT		Static speed profile
	51	N_ITER		Static speed profile
	51	M_AXLELOADCAT(n)		Static speed profile
	51	V_AXLELOAD(n)		Static speed profile
	51	N_ITER		Static speed profile
	51	D_AXLELOAD(k)		Static speed profile
	51	L_AXLELOAD(k)		Static speed profile
	51	Q_FRONT(k)		Static speed profile
	51	N_ITER(k)		Static speed profile
	51	M_AXLELOADCAT(k,m)		Static speed profile
	51	V_AXLELOAD(k,m)		Static speed profile
Permitted braking distance informatic	52	NID_PACKET	This packet requests the on-board calculation of spee	Braking curve characteristi
	52	Q_DIR		Braking curve characteristi
	52	L_PACKET		Braking curve characteristi
	52	Q_SCALE		Braking curve characteristi
	52	Q_TRACKINIT		Braking curve characteristi
	52	D_TRACKINIT		Braking curve characteristi
	52	D_PBD		Braking curve characteristi
	52	Q_GDIR		Braking curve characteristi
	52	G_PBDSR		Braking curve characteristi
	52	Q_PBDSR		Braking curve characteristi
	52	D_PBDSR		Braking curve characteristi
	52	L_PBDSR		Braking curve characteristi
	52	N_ITER		Braking curve characteristi
	52	D_PBD(k)		Braking curve characteristi
	52	Q_GDIR(k)		Braking curve characteristi
	52	G_PBDSR(k)		Braking curve characteristi
	52	Q_PBDSR(k)		Braking curve characteristi
	52	D_PBDSR(k)		Braking curve characteristi
	52	L_PBDSR(k)		Braking curve characteristi
Movement authority request paramet	57	NID_PACKET	This packet is intended to give parameters telling wh	Movement authority
	57	Q_DIR		Movement authority
	57	L_PACKET		Movement authority
	57	T_MAR		Movement authority
	57	T_TIMEOUTRQST		Movement authority
	57	T_CYCRQST		Movement authority
Position Report Parameters	58	NID_PACKET	This packet is intended to give parameters telling wh	Position
	58	Q_DIR		Position
	58	L_PACKET		Position
	58	Q_SCALE		Position
	58	T_CYCLOC		Position
	58	D_CYCLOC		Position
	58	M_LOC		Position
	58	N_ITER		Position
	58	D_LOC(k)		Position
	58	Q_LGTLOC(k)		Position
List of balises in sr authority	63	NID_PACKET		Movement authority
	63	Q_DIR		Movement authority
	63	L_PACKET		Movement authority
	63	N_ITER		Movement authority
	63	Q_NEWCOUNTRY(		Movement authority
	63	NID_C(k)		Movement authority
	63	NID_BG(k)		Movement authority
Inhibition of revocable TSRs from bali	64	NID_PACKET	This packet is used to inhibit revocable TSRs from bal	Temporary Speed restricti
	64	Q_DIR		Temporary Speed restricti
	64	L_PACKET		Temporary Speed restricti
Temporary Speed restriction	65	NID_PACKET	Transmission of temporary speed restriction.	Temporary Speed restricti
	65	Q_DIR		Temporary Speed restricti
	65	L_PACKET		Temporary Speed restricti
	65	Q_SCALE		Temporary Speed restricti
	65	NID_TSR		Temporary Speed restricti
	65	D_TSR		Temporary Speed restricti
	65	L_TSR		Temporary Speed restricti
	65	Q_FRONT		Temporary Speed restricti
	65	V_TSR		Temporary Speed restricti
Temporary speed restriction revocatic	66	NID_PACKET	Transmission of temporary speed restriction revocati	Temporary Speed restricti
	66	Q_DIR		Temporary Speed restricti
	66	L_PACKET		Temporary Speed restricti
	66	NID_TSR		Temporary Speed restricti
Track Condition Big Metal Masses	67	NID_PACKET	The packet gives details concerning where to ignore i	Track condition
	67	Q_DIR		Track condition
	67	L_PACKET		Track condition
	67	Q_SCALE		Track condition
	67	D_TRACKCOND		Track condition
	67	L_TRACKCOND		Track condition
	67	N_ITER		Track condition
	67	D_TRACKCOND(k)		Track condition
	67	L_TRACKCOND(k)		Track condition
Track Condition	68	NID_PACKET	The packet gives details concerning the track ahead t	Track condition
	68	Q_DIR		Track condition
	68	L_PACKET		Track condition
	68	Q_SCALE		Track condition
	68	Q_TRACKINIT		Track condition
	68	D_TRACKINIT		Track condition
	68	D_TRACKCOND		Track condition
	68	L_TRACKCOND		Track condition
	68	M_TRACKCOND		Track condition
	68	N_ITER		Track condition
	68	D_TRACKCOND(k)		Track condition
	68	L_TRACKCOND(k)		Track condition
	68	M_TRACKCOND(k)		Track condition

Track condition station platforms	69	NID_PACKET	The packet gives details concerning the location and l	Platform Areas
	69	Q_DIR		Platform Areas
	69	L_PACKET		Platform Areas
	69	Q_SCALE		Platform Areas
	69	Q_TRACKINIT		Platform Areas
	69	D_TRACKINIT		Platform Areas
	69	D_TRACKCOND		Platform Areas
	69	L_TRACKCOND		Platform Areas
	69	M_PLATFORM		Platform Areas
	69	Q_PLATFORM		Platform Areas
	69	N_ITER		Platform Areas
	69	D_TRACKCOND(k)		Platform Areas
	69	L_TRACKCOND(k)		Platform Areas
	69	M_PLATFORM(k)		Platform Areas
	69	Q_PLATFORM(k)		Platform Areas
Route Suitability Data	70	NID_PACKET	The packet gives the characteristics needed to enter a	Route suitablity
	70	Q_DIR		Route suitablity
	70	L_PACKET		Route suitablity
	70	Q_SCALE		Route suitablity
	70	Q_TRACKINIT		Route suitablity
	70	D_TRACKINIT		Route suitablity
	70	D_SUITABILITY		Route suitablity
	70	Q_SUITABILITY		Route suitablity
	70	M_LINEGAUGE		Route suitablity
	70	M_AXLELOADCAT		Route suitablity
	70	M_VOLTAGE		Route suitablity
	70	NID_CTRACTION		Route suitablity
	70	N_ITER		Route suitablity
	70	D_SUITABILITY(k)		Route suitablity
	70	Q_SUITABILITY(k)		Route suitablity
	70	M_LINEGAUGE(k)		Route suitablity
	70	M_AXLELOADCAT(		Route suitablity
	70	M_VOLTAGE(k)		Route suitablity
	70	NID_CTRACTION(k)		Route suitablity
Adhesion factor	71	NID_PACKET	This packet is used when the trackside requests a cha	Adhesion
	71	Q_DIR		Adhesion
	71	L_PACKET		Adhesion
	71	Q_SCALE		Adhesion
	71	D_ADHESION		Adhesion
	71	L_ADHESION		Adhesion
	71	M_ADHESION		Adhesion
Geographical Position Information	79	NID_PACKET	This packet gives geographical location information fo	Position
	79	Q_DIR		Position
	79	L_PACKET		Position
	79	Q_SCALE		Position
	79	Q_NEWCOUNTRY		Position
	79	NID_C		Position
	79	NID_BG		Position
	79	D_POSOFF		Position
	79	Q_MPOSITION		Position
	79	M_POSITION		Position
	79	N_ITER		Position
	79	Q_NEWCOUNTRY(k)		Position
	79	NID_C(k)		Position
	79	NID_BG(k)		Position
	79	D_POSOFF(k)		Position
	79	Q_MPOSITION(k)		Position
	79	M_POSITION(k)		Position
Mode profile	80	NID_PACKET	Mode profile associated to an MA	Movement authority
	80	Q_DIR		Movement authority
	80	L_PACKET		Movement authority
	80	Q_SCALE		Movement authority
	80	D_MAMODE		Movement authority
	80	M_MAMODE		Movement authority
	80	V_MAMODE		Movement authority
	80	L_MAMODE		Movement authority
	80	L_ACKMAMODE		Movement authority
	80	Q_MAMODE		Movement authority
	80	N_ITER		Movement authority
	80	D_MAMODE(k)		Movement authority
	80	M_MAMODE(k)		Movement authority
	80	V_MAMODE(k)		Movement authority
	80	L_MAMODE(k)		Movement authority
	80	L_ACKMAMODE(k)		Movement authority
	80	Q_MAMODE(k)		Movement authority
Level crossing information	88	NID_PACKET	Level Crossing information	Level crossing area
	88	Q_DIR		Level crossing area
	88	L_PACKET		Level crossing area
	88	Q_SCALE		Level crossing area
	88	NID_LX		Level crossing area
	88	D_LX		Level crossing area
	88	L_LX		Level crossing area
	88	Q_LXSTATUS		Level crossing area
	88	V_LX		Level crossing area
	88	Q_STOPLX		Level crossing area
	88	L_STOPLX		Level crossing area

Track Ahead Free up to level 2/3 trans	90	NID_PACKET	Notification to on-board that track ahead is free from	Movement authority
	90	Q_DIR		Movement authority
	90	L_PACKET		Movement authority
	90	Q_NEWCOUNTRY		Movement authority
	90	NID_C		Movement authority
	90	NID_BG		Movement authority
RBC transition order	131	NID_PACKET	Packet to order an RBC transition	Session management
	131	Q_DIR		Session management
	131	L_PACKET		Session management
	131	Q_SCALE		Session management
	131	D_RBCTR		Session management
	131	NID_C		Session management
	131	NID_RBC		Session management
	131	NID_RADIO		Session management
	131	Q_SLEEPSESSION		Session management
Danger for shunting information	132	NID_PACKET	Transmission of the aspect of a shunting signal	Movement authority
	132	Q_DIR		Movement authority
	132	L_PACKET		Movement authority
	132	Q_ASPECT		Movement authority
Radio infill are information	133	NID_PACKET		Radio infill area
	133	Q_DIR		Radio infill area
	133	L_PACKET		Radio infill area
	133	Q_SCALE		Radio infill area
	133	Q_RIU		Radio infill area
	133	NID_C		Radio infill area
	133	NID_RIU		Radio infill area
	133	NID_RADIO		Radio infill area
	133	D_INFILL		Radio infill area
	133	NID_C		Radio infill area
	133	NID_BG		Radio infill area
EOLM Packet	134	NID_PACKET		Session management
	134	Q_DIR		Session management
	134	L_PACKET		Session management
	134	Q_SCALE		Session management
	134	NID_LOOP		Session management
	134	D_LOOP		Session management
	134	L_LOOP		Session management
	134	Q_LOOPDIR		Session management
	134	Q_SSCODE		Session management
Stop Shunting on desk opening	135	NID_PACKET	Packet to stop Shunting on desk opening.	Movement authority
	135	Q_DIR		Movement authority
	135	L_PACKET		Movement authority
Infill location reference	136	NID_PACKET	Defines location reference for all data contained in th	Session management
	136	Q_DIR		Session management
	136	L_PACKET		Session management
	136	Q_NEWCOUNTRY		Session management
	136	NID_C		Session management
	136	NID_BG		Session management
Stop if in Staff Responsible	137	NID_PACKET	Information to stop a train in staff responsible.	Movement authority
	137	Q_DIR		Movement authority
	137	L_PACKET		Movement authority
	137	Q_SRSTOP		Movement authority
Reversing area information	138	NID_PACKET	Used to send start and length of reversing area to the	Movement authority
	138	Q_DIR		Movement authority
	138	L_PACKET		Movement authority
	138	Q_SCALE		Movement authority
	138	D_STARTREVERSE		Movement authority
	138	L_REVERSEAREA		Movement authority
Reversing supervision information	139	NID_PACKET	Used to send supervision parameters (distance to run	Movement authority
	139	Q_DIR		Movement authority
	139	L_PACKET		Movement authority
	139	Q_SCALE		Movement authority
	139	D_REVERSE		Movement authority
	139	V_REVERSE		Movement authority
Train running number from RBC	140	NID_PACKET	Train running number from RBC	Train characteristics
	140	Q_DIR		Train characteristics
	140	L_PACKET		Train characteristics
	140	NID_OPERATIONAL		Train characteristics
Default Gradient for Temporary Speed	141	NID_PACKET	It defines a default gradient to be used for TSR superv	Gradients
	141	Q_DIR		Gradients
	141	L_PACKET		Gradients
	141	Q_GDIR		Gradients
	141	G_TSR		Gradients
Session Management with neighbouri	143	NID_PACKET	Packet to give the identity and telephone number of	Session management
	143	Q_DIR		Session management
	143	L_PACKET		Session management
	143	Q_RIU		Session management
	143	NID_C		Session management
	143	NID_RIU		Session management
	143	NID_RADIO		Session management

Inhibition of balise group message coı	145	NID_PACKET	Indication to on-board that the balise group message	ETCS error
	145	Q_DIR		ETCS error
	145	L_PACKET		ETCS error
LSSMA display toggle order	180	NID_PACKET	Used to toggle on/off the display of the Lowest Supeı	DMI
	180	Q_DIR		DMI
	180	L_PACKET		DMI
	180	Q_LSSMA		DMI
	180	T_LSSMA		DMI
Generic LS function marker	181	NID_PACKET	Used to enable the generic toggling on/off of the disp	DMI
	181	Q_DIR		DMI
	181	L_PACKET		DMI
Default balise, loop or RIU informatioı	254	NID_PACKET	Indication to on-board that balise telegram, loop mes	ETCS error
	254	Q_DIR		ETCS error
	254	L_PACKET		ETCS error
End of Information	255	NID_PACKET	This packet consists only of NID_PACKET containing 8	End package
			It acts as a finish flag; the receiver will stop reading the remaining part of the me	

Appendix B Allocation of variables Subset-126 to categories

Packet		Variable Name	Remark	Category
Journey Profile	001	Q_JP_Status	Qualifier indicating validity of Journey Profile	Journey profile characteristics
ETCS>ATO-OB	002	N_ITER_SP	Number of iterations of SPs. If N_ITER is 0 then no data set is following.	Segment profile list
	003	NID_C (k)	Identity of the SP's country or region.	Segment profile list
	004	NID_SP (k)	SP identity.	Segment profile list
	005	M_SP_Version (k)	Identifier of the segment profile version. See Section 6.3.5.2 Segment Profile (SP).	Segment profile list
	006	Q_SP_DIR (k)	Qualifier to indicate the valid travelling direction of the SP.	Segment profile list
	007	N_ITER (k)	Number of iterations of TPs information. If N_ITER is 0 then no data set is following.	Timing point list
	008	NID_TP (k,l)	TP identity. The NID_TP is unique within a NID_C.	Timing point list
	009	T_Latest_Arrival_Date (k,l)	Date of the requested arrival time at the TP.	Timing point list
	010	T_Latest_Arrival_Seconds (k,l)	Seconds of the requested arrival time at the TP.	Timing point list
	011	T_Arrival_Window (k,l)	Acceptable time allowance to be earlier at the TP.	Timing point list
	012	Q_TP_Alignment (k,l)	This qualifier defines if the TP location is applicable from the front, middle or rear of the train.	Timing point list
	013	Q_Stop_Skip_Pass (k,l)	Specifies if the Timing Point is a Passing Point, an operational Stopping Point or a skipped Stopping Point.	Timing point list
	014	Q_TP_Information (k,l)	Specifies some information specific for the TP.	Timing point list
	015	Q_Day_Light_Saving (k,l)	This variable defines if the day light saving hour is applicable to calculate the local time.	Timing point list
	016	T_Departure_Date (k,l)	Date of the expected departure time from the Stopping Point.	Timing point list
	017	T_Departure_Seconds (k,l)	Seconds of the expected departure time from the Stopping Point.	Timing point list
	018	Q_Train_Hold (k,l)	The variable defines if the train is requested to be held at the Stopping Point or not.	Timing point list
	019	T_Minimum_Dwell_Time (k,l)	Minimum dwell time at given Stopping Point (in seconds).	Timing point list
	020	Q_Opening_Door_Side (k,l)	Specifies if the ATO-OB has to manage the train doors opening and on which side the passenger exchange doors have to be opened.	Timing point list
	021	Q_Centralised_Opening (k,l)	This variable defines if the doors are to be opened centralised or by the passengers.	Timing point list
	022	Q_Automatic_Closing (k,l)	This variable defines if the ATO-OB has to manage the train doors closing.	Timing point list
	023	N_ITER (k)	Number of iterations of Temporary Constraints. If N_ITER is 0 then no data set is following.	Temporary constraint list
	024	Q_TC_Type (k,m)	Reason for the temporary constraint.	Temporary constraint list
	025	Q_TC_Range (k,m)	Specifies if the temporary constraint starts, ends, starts and ends or covers the whole concerning Segment Profile.	Temporary constraint list
	026	D_TC_Start_Location (k,m)	Start location of the temporary constraint relatively to the beginning of the SP.	Temporary constraint list
	027	D_TC_End_Location (k,m)	End location of the temporary constraint relatively to the beginning of the SP.	Temporary constraint list
	028	Q_FRONT (k,m)	Qualifier to indicate if a speed limit given for a profile element is to be applied until the front of the train (no train length delay) or the end of the train (train length delay)	Temporary constraint list
	029	V_Speed_Level (k,m)	Value of the speed level restriction.	Temporary constraint list
	030	Q_Low_Adhesion_Rate (k,m)	Value of the braking capacity remaining.	Temporary constraint list

Segment Profile	001	N_ITER	Number of iterations of SPs in the packet. If N_ITER is 0 then no data set is following.	Segment profile characteristics
ETCS>ATO-OB	002	NID_C (k)	Identity of the SP's country or region.	Segment profile characteristics
	003	NID_SP (k)	SP identity.	Segment profile characteristics
	004	Q_SP_Status (k)	Qualifier indicating validity of Segment profile	Segment profile characteristics
	005	M_SP_Version (k)	Identifier of the segment profile version.	Segment profile characteristics
	006	L_SP (k)	Length of the segment of railway covered by the SP.	Segment profile characteristics
	007	D_EoA_Offset (k)	Distance to stop the train before an EoA.	Segment profile characteristics
	008	Q_UTC_Offset (k)	Offset to add to the UTC time in order to calculate the local time.	Segment profile characteristics
	009	M_SP_Altitude (k)	Altitude at the beginning of the SP. Considering ETRS89 as reference.	Segment profile characteristics
	010	V_STATIC (k)	Basic Static Speed Profile speed at the beginning of the Segment Profile. The variable used is comparable to V_STATIC, as defined in [Ref 2], Section 7.5.1.171.	Segment profile characteristics
	011	Q_FRONT (k)	Q_FRONT is an attribute for the speed value. It defines what to do at the end of the corresponding section if the next speed value is a “step up”.	Segment profile characteristics
	012	N_ITER (k)	Number of iterations of Specific Speed Profiles. If N_ITER is 0 then no data set is following.	Segment profile characteristics
	013	Q_DIFF (k,l)	Indicates the type of specific SSP category. The variable used is the same as Q_DIFF, as defined in [Ref 2], Section 7.5.1.102.1.	Specific speed profile
	014	NC_CDDIFF (k,l)	It is the “Cant Deficiency” SSP category for which a different value for the static line speed exists. The variable used is the same as NC_CDDIFF, as defined in [Ref 2], Section	Specific speed profile
	015	NC_DIFF (k,l)	It is the “other specific” SSP category for which a different value for the static line speed exists.	Specific speed profile
	016	V_DIFF (k,l)	Absolute Positive Speed associated to a train category.	Specific speed profile
	017	N_ITER (k)	Number of iterations of Static Speed Profiles changes. If N_ITER is 0 then no data set is following.	Static speed profile
	018	D_Location (k,m)	Location of the Static Speed Profile change relatively to the beginning of the SP.	Static speed profile
	019	V_STATIC (k,m)	Basic Static Speed Profile speed. The variable used is the same as V_STATIC, as defined in [Ref 2], Section 7.5.1.171.	Static speed profile
	020	Q_FRONT (k,m)	Q_FRONT is an attribute for the speed value. It defines what to do at the end of the corresponding section if the next speed value is a “step up”.	Static speed profile
	021	N_ITER (k,m)	Number of iterations of Specific Static Speed Profiles. If N_ITER is 0 then no data set is following.	Static speed profile
	022	Q_DIFF (k,m,n)	Indicates the type of specific SSP category. The variable used is the same as Q_DIFF, as defined in [Ref 2], Section 7.5.1.102.1.	Static speed profile
	023	NC_CDDIFF (k,m,n)	It is the “Cant Deficiency” SSP category for which a different value for the static line speed exists. The variable used is the same as NC_CDDIFF, as defined in [Ref 2], Section	Static speed profile
	024	NC_DIFF (k,m,n)	It is the “other specific” SSP category for which a different value for the static line speed exists.	Static speed profile
	025	V_DIFF (k,m,n)	Absolute Positive Speed associated to a train category.	Static speed profile
	026	G_New_Gradient (k)	Value of the new gradient at the beginning of the Segment Profile. The variable used is comparable to G_A, as defined in [Ref 2], Section 7.4.2.6.	Gradients
	027	Q_GDIR (k)	Direction of the new gradient. The variable used is comparable to Q_GDIR, as defined in [Ref 2], Section 7.5.1.110.	Gradients
	028	N_ITER (k)	Number of iterations of gradient changes. If N_ITER is 0 then no data set is following.	Gradients
	029	D_Location (k,o)	Location of the gradient change relatively to the beginning of the SP.	Gradients
	030	G_New_Gradient (k,o)	Value of the new gradient. The variable used is comparable to G_A, as defined in [Ref 2], Section 7.4.2.6.	Gradients
	031	Q_GDIR (k,o)	Direction of the new gradient. The variable used is comparable to Q_GDIR, as defined in [Ref 2], Section 7.5.1.110.	Gradients
	032	N_Radius_Category (k)	Curve category at the beginning of the Segment Profile.	Curves
	033	Q_Curve_Side (k)	Side of the curve.	Curves
	034	N_ITER (k)	Number of iterations of curve changes. If N_ITER is 0 then no data set is following.	Curves
	035	D_Location (k,p)	Location of the curve change relatively to the beginning of the SP.	Curves
	036	N_Radius_Category (k,p)	Curve category.	Curves
	037	Q_Curve_Side (k,p)	Side of the curve.	Curves
	038	M_VOLTAGE (k)	Voltage value at the beginning of the Segment Profile. The variable used is the same M_VOLTAGE as defined in [Ref 2], Section 7.5.1.78.	Electrification system
	039	NID_CTRACTION (k)	Country identifier of the traction system. It identifies the information, additional to M_VOLTAGE, required to fully define the traction system.	Electrification system
	040	N_ITER (k)	Number of iterations of voltage changes. If N_ITER is 0 then no data set is following.	Electrification system
	041	D_Location (k,q)	Location of the voltage change relatively to the beginning of the SP	Electrification system
	042	M_VOLTAGE (k,q)	Voltage value. The variable used is the same M_VOLTAGE as defined in [Ref 2], Section 7.5.1.78.	Electrification system
	043	NID_CTRACTION (k,q)	Country identifier of the traction system. It identifies the information, additional to M_VOLTAGE, required to fully define the traction system.	Electrification system
	044	M_CURRENT (k)	Allowed current consumption at the beginning of the Segment Profile. The variable used is the same M_CURRENT as defined in [Ref 2], Section 7.5.1.78.	Electrification system
	045	N_ITER (k)	Number of iterations of allowed current consumption changes. If N_ITER is 0 then no data set is following.	Electrification system
	046	D_Location (k,r)	Location of the allowed current consumption change relatively to the beginning of the SP	Electrification system
	047	M_CURRENT (k,r)	Allowed current consumption. The variable used is the same M_CURRENT as defined in [Ref 2], Section 7.5.1.78.	Electrification system
	048	N_ITER (k)	Number of iterations of balise groups. If N_ITER is 0 then no data set is following.	Balises
	049	NID_BG (k,s)	Identifier of the balise group. This variable is the same as NID_BG, as defined in [Ref 2], Section 7.5.1.85.	Balises
	050	N_TOTAL (k,s)	Number of balises in the balise group. Used as an iteration variable to describe all the balises contained in the balise group.	Balises
	051	N_PIG (k,s,N_TOTAL)	Defines the relative position in a balise group, as defined in [Ref 2], Section 7.5.1.81.	Balises
	052	D_Location (k,s,N_TOTAL)	Location of the balise relatively to the beginning of the SP.	Balises
	053	N_ITER (k)	Number of iterations of Timing Points. If N_ITER is 0 then no data set is following.	Timing points
	054	NID_TP (k,t)	TP identity. The NID_TP is unique within a NID_C.	Timing points
	055	D_Location (k,t)	Location of the Timing Point relatively to the beginning of the SP.	Timing points
	056	Q_Stop_Location_Tolerance (k,t)	Required stopping tolerance to use when the TP is a Stopping Point.	Timing points
	057	D_STP_Reached (k,t)	Distance from a Stopping Point to consider it as reached.	Timing points
	058	L_TEXT (k,t)	Length of text string.	Timing points
	059	X_TEXT (k,t,L_TEXT)	Name of the TP.	Timing points
	060	N_ITER (k)	Number of iterations of Platform Areas. If N_ITER is 0 then no data set is following.	Platforms
	061	Q_Range (k,u)	Specifies if the Platform Area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Platforms
	062	D_Start_Location (k,u)	Location of the platform start relatively to the beginning of the SP.	Platforms
	063	D_End_Location (k,u)	Location of the platform end relatively to the beginning of the SP	Platforms
	064	N_ITER (k)	Number of iterations of tunnels. If N_ITER is 0 then no data set is following.	Tunnels
	065	Q_Range (k,v)	Specifies if the Tunnel starts, ends, starts and ends or covers the whole concerning Segment Profile.	Tunnels
	066	Q_Tunnel_Category (k,v)	Category of the Tunnel.	Tunnels
	067	D_Start_Location (k,v)	Location of the tunnel start relatively to the beginning of the SP.	Tunnels
	068	D_End_Location (k,v)	Location of the tunnel end relatively to the beginning of the SP.	Tunnels
	069	N_ITER (k)	Number of iterations of Powerless Sections. If N_ITER is 0 then no data set is following.	Electrification
	070	Q_Range (k,w)	Specifies if the Powerless Section starts, ends, starts and ends or covers the whole concerning Segment Profile.	Electrification
	071	D_Start_Location (k,w)	Location of the Powerless Section start relatively to the beginning of the SP.	Electrification
	072	D_End_Location (k,w)	Location of the Powerless Section end relatively to the beginning of the SP.	Electrification
	073	N_ITER (k)	Number of iterations of Axle Load Speed Profiles. If N_ITER is 0 then no data set is following.	Static speed profile
	074	Q_Range (k,x)	Specifies if the Axle Load Speed Profile starts, ends, starts and ends or covers the whole concerning Segment Profile.	Static speed profile
	075	M_AXLELOADCAT (k,x)	Axle load from which the speed restriction is applicable. The variable used is the same as M_AXLELOADCAT, as defined in [Ref 2], Section 7.5.1.62.	Static speed profile
	076	V_New_Speed_Level (k,x)	Speed restriction to be applied if the axle load of the train ≥ M_AXLELOADCAT (k,v)	Static speed profile
	077	Q_FRONT (k,x)	Qualifier to indicate if the ALSP is to be applied to the front of the train (no train length delay) or to the end of the train (train length delay). The variable used is the same as	Static speed profile
	078	D_Start_Location (k,x)	Location of the Axle Load Speed Profile start relatively to the beginning of the SP.	Static speed profile
	079	D_End_Location (k,x)	Location of the Axle Load Speed Profile end relatively to the beginning of the SP.	Static speed profile
	080	N_ITER (k)	Number of iterations of stopping locations for unprotected level crossings. If N_ITER is 0 then no data set is following.	Level crossings
	081	D_UnprotectedLx_Stop (k,d)	Location of the stop in rear of an unprotected level crossing.	Level crossings
	082	N_ITER (k)	Number of iterations of Permitted Braking Distance areas. If N_ITER is 0 then no data set is following.	Permitted braking distance areas
	083	Q_Range (k,y)	Specifies if the Permitted Braking Distance area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Permitted braking distance areas
	084	D_Permitted_Braking_Distance (k,y)	Permitted Braking Distance value.	Permitted braking distance areas
	085	Q_PBD_SBEB (k,y)	Whether the permitted braking distance is to be achieved with the Service Brake or Emergency Brake.	Permitted braking distance areas
	086	G_PBD (k,y)	A single gradient value applicable for the calculation	Permitted braking distance areas
	087	Q_GDIR_PBD (k,y)	Direction of the gradient.	Permitted braking distance areas
	088	D_Start_Location (k,y)	Location of the Permitted Braking Distance area start relatively to the beginning of the SP	Permitted braking distance areas
	089	D_End_Location (k,y)	Location of the Permitted Braking Distance area end relatively to the beginning of the SP.	Permitted braking distance areas
	090	N_ITER (k)	Number of iterations of Switch off Regenerative Brake areas. If N_ITER is 0 then no data set is following.	Braking system restrictions
	091	Q_Range (k,z)	Specifies if the Switch off Regenerative Brake area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Braking system restrictions
	092	D_Start_Location (k,z)	Location of the Switch off Regenerative Brake area start relatively to the beginning of the SP.	Braking system restrictions
	093	D_End_Location (k,z)	Location of the Switch off Regenerative Brake area end relatively to the beginning of the SP.	Braking system restrictions
	094	N_ITER (k)	Number of iterations of Switch off eddy current brake for service brake areas. If N_ITER is 0 then no data set is following.	Braking system restrictions
	095	Q_Range (k,a)	Specifies if the Switch off eddy current brake for service brake area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Braking system restrictions
	096	D_Start_Location (k,a)	Location of the Switch off eddy current brake for service brake area start relatively to the beginning of the SP.	Braking system restrictions
	097	D_End_Location (k,a)	Location of the Switch off eddy current brake for service brake area end relatively to the beginning of the SP	Braking system restrictions
	098	N_ITER (k)	Number of iterations of Switch off eddy current brake for emergency brake areas. If N_ITER is 0 then no data set is following.	Braking system restrictions
	099	Q_Range (k,b)	Specifies if the Switch off eddy current brake for emergency brake area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Braking system restrictions
	100	D_Start_Location (k,b)	Location of the Switch off eddy current brake for emergency brake area start relatively to the beginning of the SP.	Braking system restrictions
	101	D_End_Location (k,b)	Location of the Switch off eddy current brake for emergency brake area end relatively to the beginning of the SP	Braking system restrictions
	102	N_ITER (k)	Number of iterations of Switch off Magnetic Shoe Brake areas. If N_ITER is 0 then no data set is following.	Braking system restrictions
	103	Q_Range (k,c)	Specifies if the Switch off Magnetic Shoe Brake area starts, ends, starts and ends or covers the whole concerning Segment Profile.	Braking system restrictions
	104	D_Start_Location (k,c)	Location of the Switch off Magnetic Shoe Brake area start relatively to the beginning of the SP.	Braking system restrictions
	105	D_End_Location (k,c)	Location of the Switch off Magnetic Shoe Brake area end relatively to the beginning of the SP.	Braking system restrictions

Status Report	001	M_ATO_State	The current ATO State in use.	Current status
	002	Q_STR_Indicators	Bitset with the indicators state.	Current status
	003	V_TRAIN_ATO	Current Speed of the train when the STR is sent.	Current status
	004	Driver_ID	Driver identifier number as defined in SUBSET-027 v300 §4.2.3.7.	Current status
	005	NID_C	Identity of the SP's country or region. Not relevant if D_Sending_Position = Undefined location.	Current status
	006	NID_SP	SP identity. Not relevant if D_Sending_Position = Undefined location.	Current status
	007	D_Sending_Position	Position of the estimated front end of the train at the moment the STR is sent (relatively from the beginning of the given SP).	Current status
	008	NID_C	Identity of the previous TP's country or region. Not relevant if NID_TP is undefined.	Current status
	009	NID_TP	Previous TP identity. The NID_TP is unique within a NID_C.	Cuurr
	010	Q_Pass_Stop_Depart	Qualifier to indicate if train has stopped at the TP, has departed from the TP or has passed the TP.	Current status
	011	Q_Accurate_Stopping	This qualifier specifies if the train has stopped accurately or not at the Operational Stopping Point.	Current status
	012	N_ITER	Number of iterations of TPs information. If N_ITER is 0 then no data set is following.	Timing point prediction
	013	NID_C (k)	Identifier of the next TP's country or region. Not relevant if NID_TP is undefined.	Timing point prediction
	014	NID_TP (k)	Next TP identity. The NID_TP is unique within a NID_C.	Timing point prediction
	015	T_Arrival_Date (k)	Date to arrive at the TP.	Timing point prediction
	016	T_Arrival_Seconds (k)	Estimated time in seconds to arrive at the TP.	Timing point prediction

Appendix C Allocation of variables Subset-130 to categories

Packet		Variable Name	Remark	Category
Static Train Data	5.1	Q_train _Data_Valid	Qualifier indicating validity of ETCS Data	Condition
	5.2	Q_OPERATIONAL_DATA_VALID	Qualifier indicating validity of ETCS Data	Condition
	5.4	NID_ENGINE	Identification number of train engine	Train characteristics
	5.5	D_ANTENNA	Distance of antenna from front of train	Train characteristics
	5.6	L_TRAIN	Train lenght	Train characteristics
	5.7	V_MAXTRAIN	Train maximum speed	Train characteristics
	5.8	NC_CDTRAIN	Train identification specifing the SSP to be used depending on maximum allowed cant deficiency	Braking curve characteristics
	5.9	NC_TRAIN	Train identification specifing the SSP to be used	Braking curve characteristics
	5.10	M_AXLELOADCAT	Train identification specifing axle load category to be used to compare to tracke axle load category	Braking curve characteristics
	5.11	M_NOM_ROT_MASS	Rotating mass of the train influencing the braking curve	Braking curve characteristics
	5.12	M_BRAKE_PERCENTAGE_ATO	Brake percentage from ETCS Train Data	Braking curve characteristics
	5.13	M_BRAKE POSITION_ATO	Brake position from ETCS Train Data	Braking curve characteristics
	5.14	Q_INDEX_GAMMA_CONF	qualifier indicating the set of ful service braking models preconfigured in the ETCS_OB, which are currently applicable according to the capture of the ETCS Train Data.	Braking curve characteristics
	5.15	NID_OPERATIONAL	Train number	Train characteristics
	5.16	DRIVER_ID	Identification of driver	Train characteristics
Dynamic Train Data	6.1	M_ADHESION_DRIVER	adhesion factor set by the driver	Adhesion
	6.2	Q_DIRCONTROLLER	Qualifier indicating chosen direction	Condition
	6.3	Q_APPCOND	Qualifier indicating if ETCS conditions for ATO are fulfilled	Condition
	6.4	Q_ADMODE	Qualifier indicating if ETCS conditions is in automatic driving mode	Condition
Positioning information	6.6	Q_DIRLRBG	Qualifier indicating the orientation of the train in relation to the direction of the LRBG	Position
	6.7	Q_DLRBG	Qualifier indication on which side of the LRBG the estimated ront end is	Position
	6.9	N_LOC_REF	Value of the position counter the moment of packet determination	Position
	6.10	T_LOC_REF	time at which the position counter determined	Position
	6.11	N_LOC_REFBALISE	position counter at location last relevant balise group	Position
	6.12	NID_REFBALISE	identification of reference balise	Position
	6.13	N_LOC_BALISERUNOVER1	position counter at last balise past	Position
	6.14	NID_BALISERUNOVER1	identification number of last balise past	Position
	6.15	N_LOC_BALISERUNOVER2	position counter at second last balise past	Position
	6.16	NID_BALISERUNOVER2	identification of the second last balise past	Position
	6.17	L_UNCERTAINTY_OVERREADING_LRBG	confidence interval	Position
	6.18	L_UNCERTAINTY_UNDERREADING_LRBG	confidence interval	Position
	6.19	L_UNCERTAINTY_OVERREADING_UNLINKEDBG	confidence interval	Position
	6.20	L_UNCERTAINTY_UNDERREADING_UNLINKEDBG	confidence interval	Position
Supervision Information	6.21	N_LOC_EBI	Estimated value of the position counter at the closest EBI limit	Movement Authority
	6.22	A_GRADIENT	value of acceleration due to gradient	Gradients
	6.23	N_GRAD_ITER	number of gradient changes	Gradients
	6.24	N_LOC_GRADCHANGE (k)	value of position counter at A_gradient change	Gradients
	6.25	A_GRADIENT (k)	applicable value of acceleration due to gradient	Gradients
	6.26	A_MAXREDADH	max decelration due to low adhesion	Adhesion
	6.27	N_ADHE_ITER	number of adhesion changes	Adhesion
	6.28	N_LOC_ADHCHANGE (l)	estimated value of position counter	Adhesion
	6.29	A_MAXREDADH (l)	max deceleration due to reduced adhesion	Adhesion
	6.30	A_BRAKE_SAFE	braking specification of the train	Braking curve characteristics
	6.31	N_BRAKE_SAFE_ITER	number of brake safe changes	Braking curve characteristics
	6.32	V_CHANGE_BRAKE (m)	value of speed from wich a brake safe is applicable	Braking curve characteristics
	6.33	A_BRAKE_SAFE (m)	applicable value of a brakesafe	Braking curve characteristics
	6.34	N_SEBDM_ITER	number of location changes of safe emergency brake deceleration models	Braking curve characteristics
	6.35	N_LOC_SEBDM_CHANGE (n)	estimated value of position counter from which brakesafe is applicable	Braking curve characteristics
	6.36	A_BRAKE_SAFE (n)		Braking curve characteristics
	6.37	N_BRAKE_SAFE_ITER (n)		Braking curve characteristics
	6.38	V_CHANGE_BRAKE (n, o)		Braking curve characteristics
	6.39	A_BRAKE_SAFE (n, o)		Braking curve characteristics
	6.40	V_MRSP	speed from the minimum safe front end fo the train (MRSP = most restrictive speed profile)	Movement Authority
	6.41	N_MRSP_ITER	number of mrsp iterations	Movement Authority
	6.42	N_LOC_MRSP (p)		Movement Authority
	6.43	V_MRSP (p)		Movement Authority
	6.44	Q_CONFIDENCE_INTERVAL (p)		Movement Authority
	6.45	N_LOC_EOALOA	estimated value of position counter at the end of authority	Movement Authority
	6.46	V_EOALOA	permitted speed at end of authority	Movement Authority
	6.47	N_LOC_SVL	estimated value of position counter at the supervised location, location corresponding to release speed management	Movement Authority
	6.48	T_TRACTION		Braking curve characteristics
	6.49	T_TRACTION_SPEED		Braking curve characteristics
	6.50	T_BEREM		Braking curve characteristics
	6.51	T_BEREM_SPEED		Braking curve characteristics
	6.52	V_PERMITTED	Permitted speed at current location	Movement Authority
	6.53	V_RELEASE_ATO	Current releasespeed of ETCS-OB	Movement Authority
	6.54	N_LOC_RSM	estimated value of the position counter at the "Release Speed Monitoring" location	Movement Authority
Speed and Acceleration Information	6.55	V_EST	estimated current speed	Position
	6.56	V_DELTA0	compensation of inaccuracy of the speed measurement	Position
	6.57	A_EST	current estimated train acceleration	Position
Linking Information	6.58	N_LINK_ITER	number of next linked balise groups	Position
	6.69	N_LOC_LINKNBG (q)	estimated value of position counter at the linked balise group	Position
	6.60	NID_LINKNBG (q)	identification of the linked balise group	Position

Appendix D Allocation of variables Subset-139 to categories

Packet	Variable Name	Remark	Category
Propulsion Control	Relative traction / brake request *)		Brake control
	Traction request **)	Percentage of actual traction/brake capability of the train.	Traction control
	Brake request **)	Range: -100% (full brake) .. 0 .. +100% (full traction), step ≤ 0.1%	Brake control
	Traction ready,	Auxiliary control signal for traction control	Traction control
	Traction applied,	Auxiliary control signal for dynamic brake control	Traction control
	Dynamic brake ready,	Auxiliary feed-back signal for traction control	Brake control
	Dynamic brake applied	Auxiliary feed-back signal for traction control	Brake control
Pneumatic and special brake control	Immediate train air brake request *	Auxiliary control signal for direct control of indirect (train) air brake	Brake control
	Immediate direct air brake request	Range: 0 ... 100% (full service brake), step ≤ 1%	Brake control
	Holding brake request	Auxiliary control signal for direct control of direct (locomotive) air brak	Brake control
	EB released	The signal will be active the whole time when the holding brake is requ	Brake control
	SB applied	Emergency brake not applied (main brake pipe pressure > 3.5 bar),	Brake control
	Brake cleaning active	Service brake applied (brake distributor valve output > 0.3 bar),	Brake control
	Holding brake applied		Brake control
	Special brakes enabled		Brake control
	Main brake pipe pressure	bitset: Regenerative brake enable, Magnetic brake enable, Eddy curren	Brake control
	Brake cylinder pressure	0 ... 10 bar, step ≤ 0.05 bar.	Brake control
Odometry	Raw signals from speed sensors §1)	Frequency signal for ATO-OB’s internal speed control and distance mea	Odometry
	Speed sensor status §1)	“OK” for each sensor.	Odometry
	Zero speed §1)	Auxiliary signal from vehicle (plausibility check of speed sensors). The	Odometry
	Wheel diameters §1)	Values from vehicle Range: 0 ... 1500.0 mm, step 0.1 mm	Odometry
	Standstill	signal according TSI LOC&PASS for door opening	Odometry
	Actual speed §2)	Value from vehicle Range: 0 ... 600.0 km/h, step 0.1 km/h	Odometry
	Actual acceleration §2)	Value from vehicle Range: -2500 ... 0 ... +2500 mm/s2, step: 1 mm/s2	Odometry
	Travelled distance §2)	Value from vehicle (ETCS format) Range: -231 ... 0 ... +(231 - 1) cm, step	Odometry
	Standstill	signal according TSI LOC&PASS for door opening (speed < 3 km/h, press	Odometry
Door control	Door opening mode	bitset: open L (automatically), open R (automatically), enable L (manua	Door control
	Door request	2 bitsets: bitmask for particular left door enabling / opening, bitmask f	Door control
	Door status signals	bitset: at least one L open, at least one R open, all L closed & locked, all	Door control
Train dynamics and energetics	Maximum available tractive effort (	If available in vehicle, otherwise must be entered during ATO start of n	Train characteristics
	Maximum available tractive output	special value for “Unknown”	Train characteristics
	Currently available tractive effort (c	If available in vehicle, otherwise must be entered during ATO start of n	Train characteristics
	Type of running resistance	Tractive effort at current speed as a percentage of maximum starting tr	Train characteristics
	Train mass	Predefined types of running resistances (enumerated)	Train characteristics
	T/B lever position	special value for “Unknown”	Train characteristics
	Traction force limitation	If available in vehicle, otherwise must be entered during ATO start of n	Train characteristics
	Adhesion factor reduction	special value for “Unknown”	Train characteristics

Appendix E Valid Technical Drawings

This appendix lists the valid technical drawings used in the case studies:

- 000210029 – Buitenpost versie O 11-09-2017
- 000210030 – Buitenpost – Grijpskerk versie J 11-09-2017
- 000210031 – Buitenpost – Grijpskerk versie N 05-06-2018
- 000210032 – Grijpskerk versie I 01-10-2017
- 000210033 – Zuidhorn versie R 04-03-2018
- 000210034 – Zuidhorn – Hoogkerk=Vierverlaten versie H003 10-06-2019
- 000210035 – Hoogkerk=Vierverlaten versie I002 10-06-2019
- 000210036 – Hoogkerk=Vierverlaten – Groningen versie M 29-10-2018
- 000885325 – Groningen versie AO 07-01-2019