Horizon 2020
European Union Funding
for Research & Innovation

Deliverable D 1.1
Freight specific use cases for obstacle detection and track intrusion systems

Project acronym:	SMART2
Starting date:	01/12/2019
Duration (in months):	36
Call (part) identifier:	H2020-S2RJU-OC-2019
Grant agreement no:	881784
Due date of deliverable:	Month 5
Actual submission date:	22/07/2020
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Dissemination level:	PU
Status:	Final

Reviewed: yes

Document history		
Revision	*Date*	*Description*
1	04/03/2020	Draft content and first inputs (by UNEW)
2	13/03/2020	Draft Section 3 (by UNEW)
3	20/03/2020	Revised Section 3 and summary inputs Section 4 (by UNEW)
4	23/03/2020	Pre-final Section 3 and refined use cases in Section 4 (by UNEW)
5	09/04/2020	Revised and completed Sections 3 and 4, draft Section 5 (by UNEW and UNI)
6	30/04/2020	Revised and completed Section 5 and Section 6 (Conclusions); summary document shared with IP2 and IP5 for feedback (by UNEW and UNI)
Final	22/07/2020	Feedback from IP5 integrated, final review and formatting (by UNEW and UNI)
Revised	17/12/2020	Revised version (including clarifications and additions requested by external reviewer appointed by S2R JU)

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Table of Contents

Executive Summary

This report presents the results of Task 1.1 “Analysis, assessment and definition of freight specific use cases” within Work Package 1 “WP1 Use Cases, Requirements and Specifications” of the SMART2 project. An in-depth analysis of use and operational cases has been carried out within this task to identify freight specific use cases that are relevant to development of Obstacle Detection and Track Intrusion Detection (OD & TID) systems and to define them in detail.

The introductory part comprises information about the background of the SMART2 project, in general, and of Task 1.1, in particular (in Section §1), and about the specific objective of the task (in Section §2). The following Section §3 presents the general context of the development of obstacle detection and track intrusion detection technology and consists of 2 distinct sub-sections. The first one presents the overall status of developments within traffic management in general, and the European Rail Traffic Management System (ERTMS) in particular. The second sub-section provides specific information on the development and status of Automation of Train Operation (ATO). The position and role of OD & TID technology, with respect to ERTMS and as enabler for full implementation of ATO, is discussed, with consideration to various development and implementation options for such systems.

Section §4 provides an overview of recent developments in the area of obstacle detection and track intrusion detection systems, including relevant ones that have been reported in past and/or ongoing Shift2Rail projects, but also other similar research and commercial developments that have been reported in different publications. The highlights of previous SMART project are presented in more details, because the SMART2 concept is largely based on outcomes of its predecessor.

Section §5 presents the relevant use cases (UC) that have been identified and analysed by the SMART2 consortium in relation to further development of an OD & TID system, which is the scope of the project. Potential use cases for OD & TID systems have been identified and analysed. The analysis and subsequent description of each use case has considered inputs received from stakeholders, particularly from those involved in Shift2Rail IP5. Key use cases have been selected and analysed in detail, in specific UC forms that have been included in appendices; the results will feed into the subsequent tasks in WP1, which are aimed at analysing the requirements and define specifications for the advanced OD & TID system to be developed in the project.

Finally, Section §6 draws the conclusions of the study. The potential use cases for an OD & TID system have been defined and classified with respect to **two major aspects/criteria:**

- Railway operation type that the use case relates to (mixed/general railway traffic, passengers and freight, and specific to freight operations);
- The grade of automation (GoA) for the operation of the trains.

The conclusions, which will help the SMART2 project to better define its focus and prioritise further technical activities, have been made with respect to specific criteria, including:

- Overall priority/importance of implementing the different use cases;
- Estimation of complexity of OD & TID system for the different use cases;
- Likelihood of implementation in the future;
- Relevance of SMART2 concept to the different use cases.

Abbreviations and acronyms

Abbreviation/ Acronym	Meaning
ARCC	Automated Rail Cargo Consortium: Rail freight automation research activities to boost levels of quality, efficiency and cost effectiveness in all areas of rail freight operations (S2R IP5 project)
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATS	Automatic Train Supervision
AWS	Automatic Warning System
CCS	Control Command and Signalling
CCTV	Closed-Circuit Television
DB	Deutsche Bahn (German Railways)
DSS	Decision Support System
ERA	European Rail Agency
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GIS	Geographic Information System
GoA	Grade of Automation
GSM-R	Global System for Mobile communications for Railways
HMI	Human-Machine Interface
HS/HC	High-speed/High-capacity
IP2	Innovation Programme 2 of Shift2Rail (Advanced Traffic Management and Control Systems)
IP5	Innovation Programme 5 of Shift2Rail (Technologies for Sustainable & Attractive European Rail Freight)
LADAR	LAser Detection Active Ranging
LiDAR	Light Detection and Ranging
LMA	Limit of Movement Authority
MAAP	Multi Annual Action Plan
OD	Obstacle Detection
OD & TID	Obstacle Detection and Track Intrusion Detection
OPTIYARD	OPtimised real-TIme YARD and network management (S2R IP5 project)
RADAR	Radio Detection and Ranging
RAMS	Reliability, Availability, Maintainability and Safety

S2R	Shift2Rail Joint Undertaking (under the H2020 framework)
SBB	Schweizerische Bundesbahnen (Swiss Federal Railways)
SMART	Smart Automation of Rail Transport (S2R IP5 project)
SWIR	Short Wave InfraRed
TID	Track Intrusion Detection
TMS	Traffic Management System
TPWS	Train Protection & Warning System
TSI	Technical Specification for Interoperability
UAV	Unmanned Arial Vehicle
UC-FS	Freight specific use cases
UC-GAF	General use cases, also applicable to freight
X2RAIL-1	Start-up activities for Advanced Signalling and Automation Systems (S2R IP2 project)
X2RAIL-4	Advanced signalling and automation system - Completion of activities for enhanced automation systems, train integrity, traffic management evolution and smart object controllers (S2R IP2 project)

List of figures

List of tables

Glossary of terms

Term	Definition / Description *
Active sensors	Active sensors emit energy and detect the return of that energy from the surroundings, such as radar.
Drone-based OD&TID system	Sensors mounted on a drone used for detection the objects on/near the track.
Environment Perception	Perception of objects, features and conditions in the train environment, such as infrastructure elements (e.g., signals, switches, etc., including their position, colour, etc.), which could support the train operation.
Operational Efficiency	Ratio between the outputs gained from an operation versus the inputs to the operation, such as the profit earned as a function of operating costs.
Obstacle Detection	Detection of objects on the rail tracks ahead of the train, which are not supposed to be presented on the railway tracks and present potential hazard
On-board OD&TID system	Sensors mounted onto the front profile of the locomotive, used for detection of objects on the/near the railway tracks
Passive sensors	Detect and respond to different inputs from the physical environment, such as cameras that capture reflection of sun energy in visible wavelengths or remission of energy from the objects in thermal infrared wavelengths
Resilience of Operations	The ability of a system (e.g., the railway system in our case) to resist absorb, accommodate and recover quickly from disruptions or disasters, and therefore the ability of the system to maintain services at, or return services to the same level as under normal or optimal conditions
Sensor (Data) Fusion	Method used to combine input from multiple independent sensors to extract and refine information not available through single sensors alone.
Track Intrusion Detection	Detections of objects near the rail tracks. If objects are people near the rail tracks, they represent possible intrusion if they are not authorised persons
Trackside OD&TID system	A sensor system located at or near the trackside used for detection of objects on, near, or approaching the track, which are currently or potentially obstacles, or have intruded or could intrude on the railway environment. This includes sensor systems at level crossings and other specific locations where there is an increased chance of obstacles being on the track, or track intrusions taking place.

User Interface	Interface designed to display appropriately the information from, or about the OD & TID system to meet the needs of the user, i.e., a person involved in the operation of the railway system.

* The above glossary includes a list of key specific terms that are used throughout the SMART2 project, and their definitions and/or descriptions, as adopted and used by the project consortium. It should be noted that the definitions are not strictly those in dictionary and/or standards, and some of them have been slightly adjusted to better reflect the project approach and specific use of these terms.

1. Background

This document represents the Deliverable D1.1 “Freight specific use cases for obstacle detection and track intrusion systems” of the SMART2 project, funded by the European Commission with the framework of Shift2Rail programme.

The SMART2 project is part of Innovation Programme 5 (IP5) “Technologies for Sustainable & Attractive European Rail Freight” of the Shift2Rail (S2R) programme, within the framework of Horizon 2020. In particular, according to the Shift2Rail Annual Work Plan and Budget 2019 (Shift2Rail, 2019), it is expected that SMART2 will contribute to the Technology Demonstrator TD5.1.3 - Freight ATO: Cargo.

In addition, the Shift2Rail members involved in the Innovation Programme 2 (IP2) “Advanced traffic management and control systems” are working towards the completion of Technology Demonstrator, TD 2.2 - Automatic Train Operation (ATO), which addresses general traffic, for both freight and passenger trains. Therefore, due to significant synergies with activities and developments planned in the same period in IP2, SMART2 is complementary to the IP2 project, X2RAIL4 (Advanced signalling and automation system - Completion of activities for enhanced automation systems, train integrity, traffic management evolution and smart object controllers), and will provide relevant contributions towards the achievement of D2.2_1 of IP2 - ATO (from GoA2 up to GoA4) for different Railway market segments.

In this context, the identification and analysis of freight specific use cases for obstacle detection and track intrusion detection systems, in agreement with Shift2Rail members involved in IP2 and IP5, is essential for subsequent activities in the SMART2 project.

According to use cases identified and discussed in this report, requirements and specifications will be further defined for selected use cases, in which the SMART2 concept is highly relevant. This would enable the SMART2 consortium to focus on the most promising and feasible solutions, which would be further developed and tested through a demonstrator at TRL6-7.

2. Objective

This document has been prepared to present the outcomes of work carried out in Task 1.1 “Analysis, assessment and definition of freight specific use cases”, within Work Package 1 “WP1 Use Cases, Requirements and Specifications” of the SMART2 project.

The specific objective of Task 1.1 is to identify and analyse freight specific use cases that are relevant to development of Obstacle Detection and Track Intrusion Detection (OD & TID) systems. An in-depth analysis of freight specific use and operational cases has been carried out within this task for the purpose of identifying those cases that are relevant to development of SMART2 OD & TID system. The focus was on use cases that have been identified by end-users (IMs and RUs) and industry stakeholders from S2R members in IP2 and IP5.

Key use cases have been selected and analysed in detail, and the results will feed into the subsequent tasks in WP1, which are aimed at analysing the requirements and defining specifications for the advanced OD & TID system to be developed in the project.

3. The Context - Current Developments in Railway Traffic Management System

The common linked goals of current mainstream developments in railway traffic management systems are increases in capacity and efficiency, and transition from infrastructure-based train control to automation of train operation. The current strategy in Europe is to develop the European Rail Traffic Management System (ERTMS) and the signalling and control component of the ERTMS, the European Train Control System (ETCS), to increase capacity and as a foundation for automation of trains on national and international networks. It is envisaged that the implementation of Automated Train Control (ATC) will be through increasing the functionalities of ERTMS developed and implemented to higher levels and addressing the gaps and challenges to enable ATC, although the implementation might be in stages with different grades of automation.

3.1 Increased Efficiency and Resilience of Operations

To realise traffic control across railway network in different countries in Europe, ERTMS was raised to harmonise Control, Command, Signalling and Communication system across the Europe and improve compatibility among different railway operators in Europe. In current stage, ERTMS is designed as a single European signalling and speed control system that ensures interoperability of the national railway systems, reducing the purchasing and maintenance costs of the signalling systems as well as increasing the speed of trains, the capacity of infrastructure and the level of safety in rail transport. ERTMS comprises the European Train Control System (ETCS), i.e., a cab-signalling system that incorporates automatic train protection (ATP) and the Global System for Mobile communications for Railways (GSM-R), which provides voice communication for train drivers and signallers and data communication for ETCS. In addition, operating rules and relating technical specifications are published in the Control Command and Signalling (CCS) Technical Specification for Interoperability (TSI). ERTMS and GSM-R rules are published in the Operation and Traffic Management TSI.

To upgrade current ERTMS with more functionality on traffic management, the traffic management section should extend its interfaces with more information from/to the network, which would digitalise all the required data resources for its further process and optimisation. A novel railway traffic management system (TMS) should have interfaces with trackside and on-board ETCS system, trackside objectives (including crossing control, intelligent infrastructure, Automatic Warning System (AWS), Train Protection & Warning System (TPWS), position balise and others), GSM-R, CCTV, etc. With the support of information from the network, the TMS can monitor the controlled network with more details and generate optimised railway operation solutions taking into account different disturbances or disruptions in the network by applying optimisation approaches, which improve efficiency and resilience of railway daily operations. The whole process of decision-making can be viewed as a closed loop from digitisation of traffic management (information collection) to automation of traffic management (traffic optimisation) which are introduced in section 3.1.1 and

3.1.2, respectively.

3.1.1 Digitisation of Traffic Management

Digitising information related to traffic management and train operations, including locations of trains, speed of trains, timeliness of services, timetables, routes (start, end and calling points), train and infrastructure defects and failures, maintenance requirements and operations, weather conditions, passenger information etc.

3.1.2 Automation of Traffic Management

Automating traffic management enables the implementation of traffic management software which can optimise the operation of the railway, rapidly processing and considering large amounts of disparate data streams to find the optimised traffic management solution. The volume of data relating to many different types of conditions relating to traffic management which can be processed by automated traffic management systems, and the speed at which it can be processed far exceed the capabilities of a human, therefore potentially enabling optimal decision making. However, the quality of the automated decision making depends on the decision-making algorithms employed, these algorithms and methods to test them are being developed.

3.2 Automation of Train Operation (ATO)

The automation of train operation was gradually developed to enforce signal commands so that drivers could not allow trains to pass beyond their limit of movement authority. Originally, "Automatic Train Control" (ATC) was the term used for warning systems tried on some lines before the general introduction of the AWS (Automatic Warning System) in the 1960s. Automatic Train Control (ATC) has been further adopted worldwide to describe the architecture of the automatically operated railway. The more modern ATC concept refers to the whole system that includes all the other automatic functions; for some of these functions it may also include a degree of manual intervention. Therefore, the ATC package includes ATP (Automatic Train Protection), ATO (Automatic Train Operation) and ATS (Automatic Train Supervision).

The Automatic Train Protection (ATP) is a type of train protection system where the train is given a Limit of Movement Authority (LMA), based on the train’s speed, its braking capability and stopping distance. On automated trains, the data for the traffic authority is transmitted to the train, where the on-board computer process the information along with train data such as the current speed, braking system parameters, etc. and calculates the target speed that the train must reach and by when, in the form of a braking curve.

The Automatic Train Operation (ATO) is the driving part of an ATC system. At manually driven trains, the driver initiates the starting of the train, controls its acceleration according to the permitted speed and stops at designated stations in the correct locations. The ATO system is designed to perform these parts of the operation, except for that the driver normally initiates the train start.

The implementation of ATO is expected to have many advantages; it enables the Traffic Management System (TMS) to have direct input to train control allowing the trajectories of trains to be optimised. This means that the speed of trains can be regulated to avoid the need to stop and start due to a preceding train, instead their speed can be regulated to maintain a safe distance from the preceding train and arrive at the point where the preceding train clears its path at the correct moment. This reduces the energy requirement for operating the trains and improves the throughput of trains increasing capacity and resilience to disruption. Fully automated train control also enables the driver to be replaced with technology, reducing operating costs.

The five commonly used grades of automation are shown below in Table 1. Obstacle and track intrusion detection are key requirements for the levels of automation which have control over the motion of the train and operation in case of disruption. However, the course categories in Table 1 might need some refinement for detailed consideration since an automated obstacle detection system might be involved in stopping a train in an emergency, but the stopping of the train in normal operation might be controlled by the driver or an automated system. Similarly, in a GoA grade 3 system an automated obstacle detection system might have the primary responsibility for detecting obstacles and stopping the train in normal operation, in case of disruption an attendant might have the primary responsibility for this function.

Table 1: Main characteristics of the five Grades of Automation (GoA)

Grade of Automation		Door Closure	Setting train in motion	Stopping train	Operation in case of disruption
GoA 0	Run on Sight (ROS)	Driver	Driver	Driver	Driver
GoA 1	Automatic Train Protection (ATP)	Driver / Automatic	Driver	Driver	Driver
GoA 2	Semi-Automatic Train Operation (SATO)	Driver	Automatic	Automatic	Driver
GoA 3	Driverless Train Operation (ATO-DTO)	Attendant	Automatic	Automatic	Attendant
GoA 4	Unattended Train Operation (ATO-UTO)	Automatic	Automatic	Automatic	Automatic

Figure 1 shows a schematic representation of the roles of systems in ATO with GoA 3-4, with GoA 1-2, most of the on-board functions (except for ATP) and the “Track-clear Detection” being performed by the driver.

In order to cope with accelerated growth in passenger and freight transport on European railway networks, the European Rail Agency (ERA) is looking forward to upgrade automation level from existing GoA1/GoA2 to GoA3/GoA4. Some metro trains have been already implemented with

GoA1/2, and this helped to better use the existing infrastructure by optimising and increasing the number of the train per hour on dedicated lines. As the system for metro is quite simple and the parameters are restricted to a dedicated route, the operational accuracy can be achieved with optimal energy consumption. Automated operation could also lead to decrease operation and maintenance costs, while reducing the reliance on the cabin operator through the use of a robust control system.

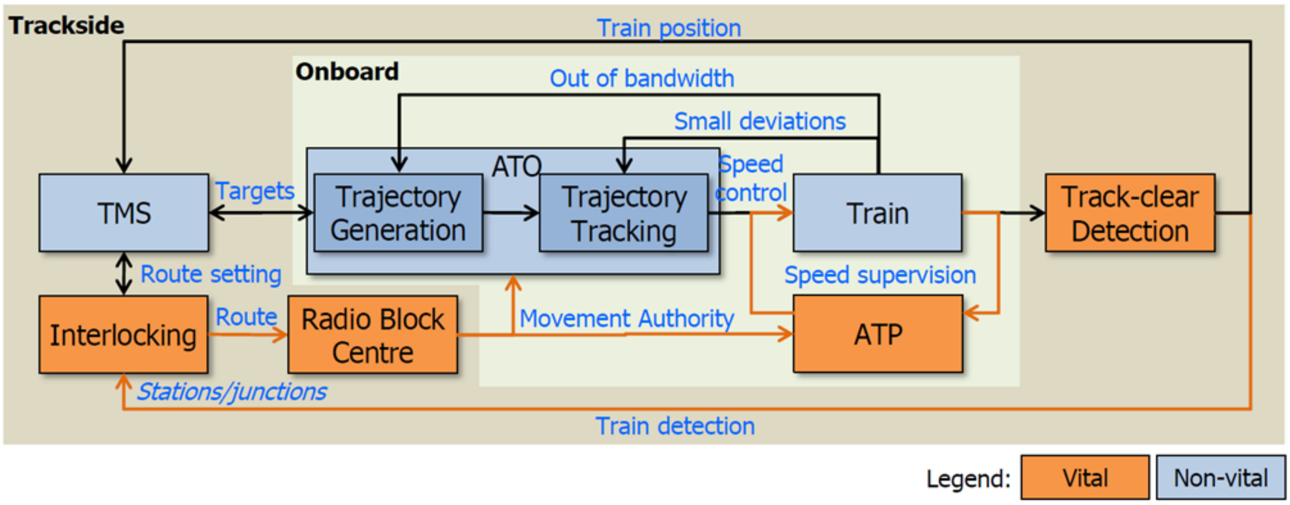

Figure 1: Driverless/Unattended operation (GoA 3-4) (Goverde, 2019)

The current state of implementation of ATO is that GoA 3/4 implementations are largely limited to metro systems and some heavy haul systems. The main reasons for these implementations being feasible are that they are closed systems, where vehicles are largely dedicated to a contained system of track, infrastructure, signalling and control system (often owned by the same operator) with little or no interaction with other systems, and often there is relatively little risk of obstacles on the track or track intrusion. Therefore, a dedicated ATO system can be developed and implemented to their specific operational purpose, and there is relatively little risk of obstacles on the track or track intrusion is due to the fact that a lot of metros are usually travelling in tunnels or other inaccessible areas with access points being largely limited to stations where specific mitigations measure to detect passengers or staff accessing the track can be implemented. For heavy haul the lower risks can be due to the remoteness of the areas the lines run through. These issues and risks are compared to national and international networks where the scale is much larger (in terms of infrastructure and number of vehicles), vehicles from different operator must be compatible to operate over large areas, possibly including more than one infrastructure manager. Also these networks include a wide range of conditions including, urban, rural and remote areas with a wide range of hazards from the external environment and outside human sources (unauthorised, access, road vehicles at crossings) meaning that there are a wider variety of risks that need to be mitigated against.

To be fully functional on the mainline, an ATO model will require both trackside and onboard equipment, including key subsystems such as:

- On-board train control;
- TMS for constant updating of regulation schedules (timetabling and decision-making);
- Balise positioning;
- GSM-R and speed probes on axles, etc.

Speed measurement and accuracy is essential for successful ATO.

Any GoA 3 or 4 application will also need supporting systems and technologies for accurate speed measurement, detection of hazards (obstacles and/or intrusions), creep facilitation, automatic sleep and wake-up commands for effective berthing, automatic joining or splitting of trains and automatic detrainment in the event of an incident. All of these present real challenges.

3.2.1 ATO Contribution to Increase Efficiency and Resilience of Operations

Another potential advantage of ATO is as part of an overall automation of railway operations strategy which would enable increases in efficiency and resilience of operations. This requires digitising information related to traffic management and train operations so that optimal decisions can be made (manually or automated) regarding the most effective way to react to the conditions. The information related to traffic management and train operations which needs to be digitised for automation of traffic management as well as ATO includes, locations of trains, speed of trains, timeliness of services, timetables, routes (start, end and calling points), train and infrastructure defects and failures, maintenance requirements and operations, weather conditions, passenger information etc.). Automatic traffic management enables the implementation of traffic management algorithms which can optimise the operation of the railway based on large amounts of real-time data streams and find an optimised traffic management solution. The real-time data feed can include information from multiple equipment in railway circumstance which helps traffic management entity configure current traffic condition in its controlled area and make real-time decision to with applied algorithm. Usually, the information is fed with high frequency which far exceeds the capabilities of a human to process, therefore potentially enabling optimal decision making. However, the quality of the automated decision making depends on the decision-making algorithms employed; these algorithms and methods to test them are still open questions in railway industry and being developed.

Block chain automation is specific high level process potentially applicable to railway traffic management, although it is more relevant to automating processed related to logistics, demand, service provision, booking and scheduling, than moment to moment traffic management, but data could also be useful for setting traffic management priorities and longer term traffic management strategies (e.g. assigning traffic to specific days).

3.2.2 Pathway to Automation on National and International Railway Networks

The pathway to automation on national and international rail networks requires standardised (or cross-compatible) developments and integration of all ATO sub-systems into standardised (or cross-compatible) ATO system(s) suitable and fully capable for operation of national and international rail networks.

In terms of train control and safety supervision (signalling and movement authority), the expected strategy it to continue the development of the European Rail Traffic Management System (ERTMS) and the signalling and control component of the ERTMS, European Train Control System (ETCS), and ensure that the local on-train control systems are compatible with it. There are three levels defined for ERTMS, all levels continuously supervise the train:

Level 1 - does not have continuous communication between train and trackside, lineside signals are necessary and train detection is performed by the trackside equipment;

Level 2 - has continuous communication between the train and trackside, lineside signals are optional, and train detection is performed by the trackside equipment;

Level 3 - also has continuous communication between the train and trackside, the main difference with level 2 is that the train location and integrity is managed within the scope of the ERTMS system (not the trackside) and there is no need for lineside signals.

Within ERTMS Levels, there is a further distinction, i.e., between fixed block and moving block. A block is a division of the track into sections which trains are authorised to occupy and move into; the TMS uses the regulation of the authority of trains to move into blocks to ensure safe separation between trains. Since level 2 is dependent on trackside systems to locate the train, the number of blocks, and hence capacity of the line is physically limited by the number of detection systems. The capacity can be increased in level 2 by increasing the number of detection systems; however, there are economic, practical, and reliability issues with installing more detection system. In level 3 there is no limit on the number and location of the blocks (up to the resolution of the train positioning system), these can be Fixed Virtual Block, or full moving blocks as represented in Figure 2 and Figure 3. Fixed Virtual Blocks relies on the use of virtual fixed sections, the movement authority of the train being extended to include the next free block up to a preceding train, blocked junction or destination. In Full Moving Block the movement authority is extended dynamically as the position of the preceding train is updated and the maximum safe extent of the movement authority (including a safe separation distance) is updated continuously.

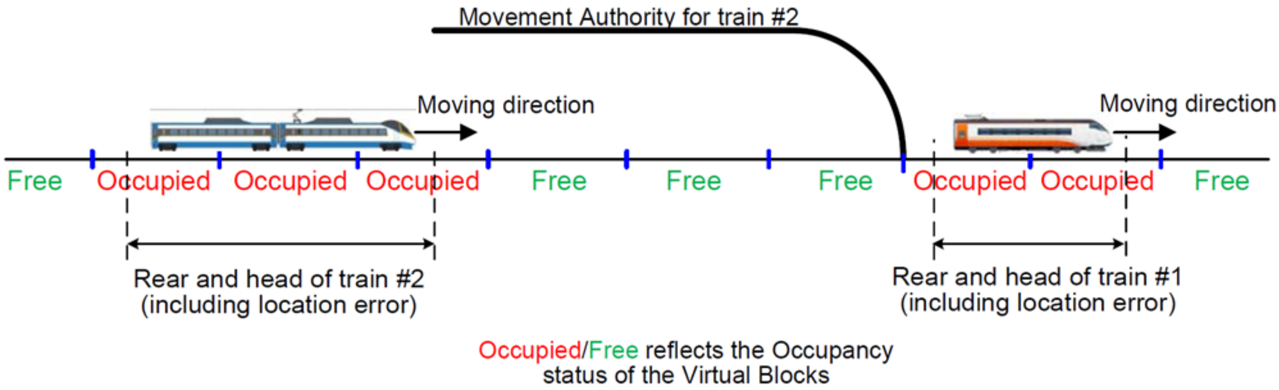

Figure 2: Virtual Block system (Furness et al., 2017)

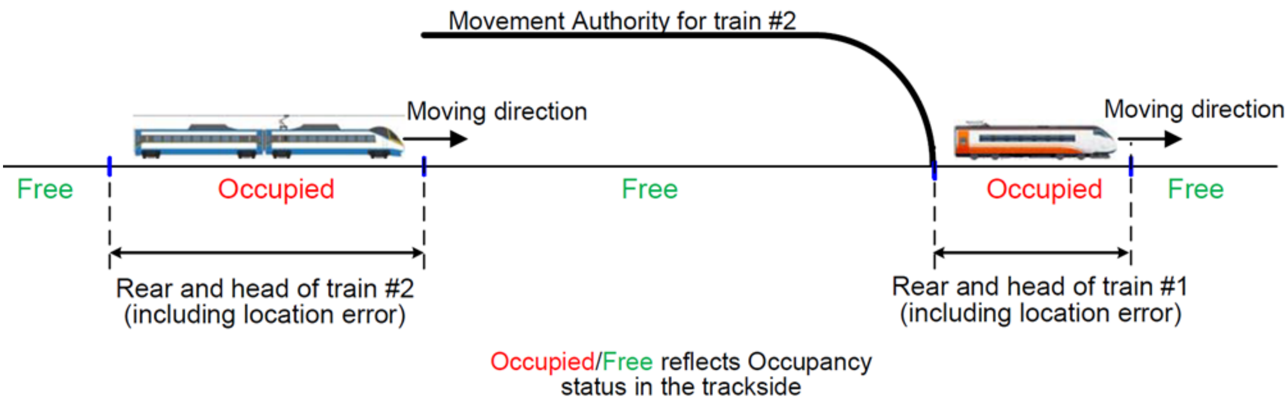

Figure 3: Full Moving Block system (Furness et al., 2017)

In terms of train control, the train control system controls the movement of the train within the limit of the movement authority, at the very least regulating speed so that the train can stop before exceeding the current movement authority. Within the minimum necessary train control there are other train control strategies which can be implemented, for example the speed of a non-stop freight train following a stopping passenger train can be regulated based on the predicted average speed of the passenger train, allowing the following to maintain a constant speed rather catching the preceding train and having to slow down to maintain minimum safe separation and waste energy accelerating again. Such train control strategies can be most efficiently and effectively implemented with ATO, although the TMS giving the driver a speed profile to follow (rather than fixed signals to obey) is another option.

Although the implementation of ATO is possible on routes managed by ERTMS level 2, the full benefits of implementing ATO as part of an overall automation of railway operations strategy, including automated TMS, in terms of capacity and efficiency increases are only available with ERTMS level 3.

3.2.3 Challenges for Implementation of ATO

There are numerous challenges for implementing ATO related to its different subsystems and their required functions. However, there are defined and developed technical solutions for train control, the main challenges in these areas are economic and political related to cost and standardisation. The challenges for automated traffic management mainly relate to the development of intelligent automated traffic management with optimally efficient automated decision making, automatically implementing a fixed timetable is already feasible. As mentioned previously, the development of intelligent automated traffic management with optimally efficient automated decision making requires the digitisation of all the relevant information to traffic management. One of the most significant challenges in the development of ATO is the development and integration of automated obstacle detection systems which are able to match or exceed the capabilities of the driver at detecting obstacles and other hazards in the path of the train and intervene in the operation of the train, and it is these challenges which will be focused on in this report. In addition to the challenges common to any train operating on the mainline network, there are also challenges associated with specific conditions and operating situations, such as the operation of freight trains and marshalling yards.

The role of obstacle detection and track intrusion detection systems (OD & TID) in the automation of train operation is to fulfil the obstacle detection functions currently carried out by the driver. Automated obstacle detection systems have the advantage that they do not have to be based on a single location, as when relying on the driver for these functions, they can be disperse around the trackside as well as on the train and the combined input used to build a picture of the situation for each train. Obstacle detection systems detect objects in the path of the train, close to the path of the train which could pose a hazard, or tack objects (such as cars at level crossings) which could pose a hazard to the train in the future. A sub-set of obstacle detection are track intrusion systems, these detect when an object, vehicle or person crosses a defined boundary (property boundary or platform) into an area where they or a passing train might be put at risk. Currently, a common track intrusion system is the type of those installed at metro stations (with or without ATO) to detect passengers or staff passing from the public areas to the restricted areas (i.e. from the platform to the track). The role of the OD & TID systems are to detect anomalous objects and situations, and in some cases assess and classify the object or situation, so that the train control system (which could involve the on-train control system, the off-train control system ETCS or both) can implement the appropriate response, such as stopping approaching trains, reducing their speed or movement authority or sounding the audible warning device. In mainline operation where the movement of trains is centrally controlled, the primary role of OD & TID is not the detection of other trains, since the safe separation of trains is managed by the ATO, however in other situations such as marshalling yards it might also have a role in detecting trains and tracking other objects and features.

3.2.3.1 Common challenges

Common challenges related to all types of trains operating under ATO on national and international networks are:

- Large variation in types of surrounding environment with associated large variety of hazards – greater variety than most current ATO implementations, for example, metros mostly running in tunnels or fully fenced from the public;
  - Differences between urban, rural and remote environments have greater variation in conditions and hazards, such as people and vehicle traffic at level crossings, greater access or reduced barriers to trespass, objects falling from bridges, fallen trees, landslides and debris, large animals intruding on the trackside, etc.;
  - This means that the OD & TID system needs to reliably detect and identify a wide variety of hazards from obstacles or intrusions, and appropriate responses determined and implemented for each. There could be significant differences in the appearance and behaviour of hazards across different regions and seasons. For example fallen trees might

appear different in different seasons and dynamic objects such as wildlife which might vary significantly in terms of hazard (large animals (horses, cows, etc. being a significant hazard) or small animals (birds, rodents, etc. being less significant hazards)) and behaviour across different regions and seasons;

- Environmental conditions can significantly affect train performance, particularly adhesion between the wheel and the rail, a fully effective and efficient ATO would need to respond correctly to these conditions;
- Extensive networks require train control communication and OD & TID over large areas, which increases the area to be monitored or controlled to permit the safe passage of trains, as well as the opportunities for incidents. Also, the larger the network the less feasible it is to implement effective barriers to prevent track intrusion by unauthorised persons, e.g. strong and high fences;
- Providing adequate detection coverage ahead of a train to enable the driver or control system to react and to allow that reaction to be timely enough to prevent or mitigate the consequences of an incident. This is particularly the case where the view of the route ahead and possible sources of hazards (e.g., level crossings) are concealed from the perspective of the driver or front of train by environmental features, such as tunnels, cuttings, buildings, trees, or other obstructions to the view, especially in combination with curves in the route preventing direct line of sight. The distance and area of detection coverage ahead of any train will vary depending on the reaction time of the driver/control system, and the speed and braking performance of the train;
- Large variety of vehicles using the network, all of which must be compatible with the method or ATO implementation (preferably standardised), including train control, traffic management and OD & TID systems;
- Compatibility and interoperability of ATO systems - Vehicles must be compatible with all ATO systems on their route, and infrastructure operating different systems or operated by different infrastructure manages must at least be able to exchange data related to train movements across boundaries;
- The ATO must meet safety requirements and obtain safety certification, according to standard EN 62267:2009 (CEN, 2009), which states that an obstacle detection device could be mounted on train or trackside;
- Large distance between and issues which might be detected and available staff to respond to incidents. For example if an object is detected intruding on the track at a metro station, there is likely to be a member of staff nearby, which can investigate the situation identify the object (empty plastic bag, item of luggage, or person) and initiate an appropriate response, therefore at TID or OD system that only detects objects might be sufficient. However on a remote section of a national network the nearest member of staff might be many kilometres away, therefore

it would be more critical for the OD & TID systems to be able to identify objects and classify the risk to trains they present so that appropriate measures can be taken automatically, and staff attendance at an incident is only required for the most severe cases;

- Handling situations were staff, equipment, and perhaps automated equipment, legitimately access the trackside environment whilst trains are operating. Detecting people and objects on or close to the track and distinguishing hazardous situations from situations were trains can pass safely;
  - Some networks implementing ATO stop operating trains before staff access the tracks to perform maintenance;
  - On national and international networks, staff access the track and immediate trackside environment for inspection and maintenance activities while trains are operating.
- Developing OD systems which match or exceed the capabilities of drivers in most situations;
- Integrating OD from front of train and trackside sensors (automated OD is not limited to just using the drivers' perspective);
- Implementing TID at high risk locations (such as level crossings) and along long stretches of track;
  - Identifying hazardous situations, including predicting the behaviour of people, vehicles, and objects.
- Detecting and responding correctly to intrusion of objects and material from the environment, and environmental conditions, e.g., snow, water over the track, fallen leaves (either on the rail or airborne in front of the train);
- Development of identification and classification algorithm for OD & TID system (especially TID system) should be designed to take account of the unpredictable behaviours of moving objects (like humans and animals). The OD & TID should determine hazard levels for different moving objects and determine whether it is predicted to move out of, or into the path of the train in the immediate future. Also, appropriate reactions and procedures to assigned hazard levels, such as performing an emergency stop for detection of a situation with a high hazard level should be determined and implemented as part of the integration of the OD & TID system with the operation of trains.

3.2.3.2 Challenges specific to automation of rail freight

Many of the challenges associated with implementing ATO are common to all types of trains, passenger, high speed, freight and infrastructure maintenance trains, however, some challenges are specific, or of greater relevance to rail freight:

- The composition of freight trains varies significantly between trains, this has means that the performance and behaviour of freight trains varies much more than passenger trains, for example and the ATO system must be able to take these into account efficiently (assuming all freight trains had the performance of the worst case scenario would be inefficient).

- Demand for passenger services is higher during the day, therefore freight rail services might have a higher proportion of the route capacity allocated to them during the evening, night-time and early morning Therefore, the OD & TID should also have good performance in the conditions which exist at these times of day. Also, there will be a variation in types of hazard at these times of day, such as the types of wild animals (e.g., nocturnal animals that are more active at night).
- Whilst some passenger services are limited to shorter urban routes, freight train routes (along with long distance passenger services) tend to be over long distances. On long distance routes, through remote areas, intrusion by large animals (such as cows, horses, deer, etc.) might be a common occurrence and, therefore, more of an issue for freight trains than passenger trains, in general. In addition, freight trains might more commonly use older or less well-developed routes with anti-intrusion measures (e.g., fences) that might be less extensive or less well maintained, making both animal and human (i.e., trespassers and vandals) intrusions a common occurrence and, therefore, more of an issue for freight trains.
- The length and number of vehicles of each train can vary and be modified, significantly, even during a single trip.
- The weight of the train varies much more between fully loaded and empty, having a greater impact on performance, even the same train can change its weight from fully loaded to empty during a trip (e.g., automated discharge of bulk cargo).
- The service types of freight and passenger trains are heterogeneous, e.g., for freight trains there might be a greater focus on optimising energy consumption rather than punctuality, except where the punctuality of freight trains affects that of passenger trains. As a result, an ATO system with higher GoA level will prioritise efficiency of the operation of freight train, which would be a promising feature for freight operators.
- Generally, freight trains take much longer to accelerate due to a lower power to weight ratio.
- The maximum loaded weight of freight vehicles is often much greater than passenger vehicles.
- The breaking performance of most freight trains is significantly worse than passenger trains, even using the same braking technology the greater maximum weight of freight vehicles means that there is more energy to dissipate limiting the braking performance that can practically be achieved. Also braking control is much more basic on conventional freight trains relying on propagation of air pressure along a train, meaning that (along with variations in weight) different vehicles can be applying different levels of brake force introducing significant longitudinal forces into the train. Since freight trains rarely operate at speeds in the 160-200km/h or higher speed range, it is usually advance notice of a hazard or intrusion, in terms of distance ahead of a train, that is most significant, rather than reaction time of the driver or

control system. Therefore, the OD & TID system should provide accurate detection, identification and classification of obstacles on and around the track, so that the appropriate actions can be implemented, for example, breaking if collision with a significant obstacle is predicted. For example, an empty plastic bag would be an insignificant obstacle and a bolder would be a significant obstacle.;

- The longitudinal rigidity of freight trains is lower than passenger trains. Freight trains are generally composed of multiple individual wagons (or articulated/permanently coupled sets of wagons) coupled together, the conventional buffers and screw coupling arrangement has significant slack and shock absorbing properties. This, along with the basic brake control, can lead to introducing significant longitudinal forces into the train and some portions of the train travelling at different speeds to others as the couplings extend and compress throughout the train, in extreme cases this can lead to derailment where the lateral or vertical reactions to the longitudinal forces exceed the lateral or vertical constraining forces at the wheel rail interface or due to the weight of the vehicle, particularly if emergency braking is applied without due consideration to the potential for derailment. Passenger trains often operate in fixed sets with more rigid couplings between sets of vehicles;
- Some freight trains carry hazardous substances (flammable fuels, toxic chemicals, etc.) which could have a serious impact on staff and public safety, and the environment if there was an incident. To operate these trains safely under ATO the monitoring and intervention roles of the driver, and the modifications to driving strategy would have to be performed by automated systems or a non-driving attendant;
- The multiple factors relating to the control of freight trains, weight, length, braking, acceleration, controlling the slack (compression/tension between vehicles and cargo, are currently considered and taken into account, in combination with the environmental conditions etc., by the driver to determine the appropriate control inputs based on training, experience and judgement. An ATO system would have to be provided with the relevant inputs and include mechanisms to take these factors into account, including the use of OD & TID systems.

3.2.3.3 Challenges specific to automation of marshalling yards

Some of the challenges related to ATO and the operation of marshalling yards and depots are common to both passenger and freight operations, however in general the situation in freight yards is more challenging than passenger train depots as the challenging situations are more diverse are encountered more frequently, and form a core part of the operational activity. Additionally, ATO of freight trains has challenges related to the loading and unloading of freight trains which are distinct from the loading and unloading of passengers. There would be two main approaches to meeting these challenges one would be to adapt ATO to operate with the current manual or non-integrated system procedures for shunting, coupling and loading/unloading, the other would be to automate the processes in the marshalling yard and fully integrate them with the ATO. Automation of marshalling yards would make integration of ATO and with marshalling yards more efficient and further the overall objectives of ATO, i.e. increasing the competitiveness of the rail transport mode. Optimising the operation in marshalling yards will be a logistics, as well as a technical problem; the OPTIYARD project worked on developing software optimisation module and algorithms for large and complex freight transport networks, which integrate well with IP5 activities towards automation, e.g., intelligent assets and automated shunting and mainline operations (Liu et al., 2018). This included simulation of real-time yard management, interaction with the network and ad-hoc timetable planning. Some specific challenges of ATO in marshalling yards and automation of marshalling yards are:

- Train control in marshalling yards has different characteristics to mainlines, particularly as on mainlines the occupancy of the track, route setting, and position and speed of every train are reported to the TMS;
- In terms of OD & TID systems, the challenges are:
    - Detecting, identifying and classifying objects in the marshalling yard or loading/unloading environment;
    - In many situations when forming trains and positioning vehicles the locomotive will not be the leading vehicle, therefore OD systems on the locomotive would not have line of sight to obstructions in the path of the train, which means that alternative obstacle detection solutions would be required;
    - In marshalling yards, it is possible that OD systems might have a role in detecting distances between vehicles, either to detect them as obstacle or to manage bringing them into controlled contact for coupling. This functionality could be fulfilled by specific range/distance measuring devices, in either case the OD, or the processing of the result of the OD, would require development to take account of this situation.
- Developing processes and algorithms for automated systems to determine an appropriate action to be taken based on OD & TID. Some objects might be unexpected hazards, others might be expected objects (e.g. unloading infrastructure or personal performing critical operations) which might or might not be in a hazardous position or condition. The ATO and/or automated yard operation system would have to make decisions and take actions based on the inputs from sensors and system status information. The detection and decision-making process would be quite complex in the case were operators and equipment are necessarily in close proximity to moving vehicles, in order to detect hazardous situations correctly and avoid false alarms when there might be very small margins between normal and hazardous situations. Particular attention would need to be paid for developing detection systems, algorithms and processes for detecting staff in marshalling yards, which might appear suddenly, inadvertently, and/or unawares in the path of a train and be hazarded by the train, or might intentionally and necessarily be in the immediate vicinity of the train or its path but similarly be hazarded by it.

- Currently in Europe the standard coupling system for freight wagons is the conventional buffer and screw coupling which require manual connection of the coupling and brake systems, also the manual application/release of the parking brake after uncoupling and coupling respectively. Development work for different forms of automatic coupling for freight trains, including automated coupling of brake systems and additional electronic system has been carried out and proposals made, however there are significant issues related to cost and interoperability to be overcome. In addition, solutions would be required for interfacing the control of the automated couplings with the automated yard and train control systems (as well as TMS oversight of train integrity).
- Solutions for identification of individual vehicles in a yard and their position would be essential, as would solutions for determining the status of and doors, loading or dispatch hatches, or other safety critical status regarding the condition of the wagons. Also, identification and monitoring of the status of the condition of the freight in/on the wagons would be an advantage. These solutions would also need integrating with the yard automation system.
- In basic marshalling yards route setting is carried out manually by operatives on the ground, although there is some automation in some cases with either a human operator or automatic system determining the route to be set.
    - The same systems used for obstacle detection could also be developed to include the functionality of detecting and confirming the route set in marshalling yards, for example a vision-based obstacle/route detection system. However, whilst some form or route detection would be necessary for ATO in yards, it depends on the system architecture determined where this function would be carried out, by train mounted systems or the infrastructure, and the communication paths and decision-making process used. Alternatively, the function could be carried out based on a synthesis of inputs from different systems.
- The system would need to be saleable and affordable, significant investment in automation in large marshalling yards might be justifiable, however where the infrastructure is a private industrial site with a single siding only capable of handling a few vehicles connected to the mainline network. Therefore, solutions for small sidings and yards at least compatible with ATO might also be necessary.

3.2.4 Obstacle Detection and Track Intrusion Detection System

Obstacle detection (OD) is an integrated system which detects objects in front of a vehicle during its movement via sensors, data structures, and algorithms (Matthies, 2014). An OD system is designed for safety critical applications and has a wide application in autonomous vehicles and robotics. In the railway domain, the function of an OD system is to detect static/dynamic objects, which the railway vehicle is on a collision path with, or are on a collision path with the railway vehicle.

The sensors used for OD can be divided into two groups: passive and active. Passive sensors, which detect and respond to different inputs from the physical environment, such as cameras that capture reflection of sun energy in visible wavelengths or remission of energy from the objects in thermal infrared wavelengths. Active sensors, which use their own energy sources, such as radar that emits energy and detect the return of that energy from the surroundings.

Besides the obstacle detection, in safety critical applications, such as railway applications, it is of crucial importance to estimate the distance of the obstacle to the vehicle. There are numerous passive OD systems developed, which can be divided based on distance estimation method into following two categories:

- the depth information of the objects is extracted using stereo imaging,
- distance estimation from single cameras.

Although stereo vision-based distance estimation is by far the most widely used method for distance (depth) estimation in the computer vision community, in applications such as railway, where the long range distance estimation is necessary, the stereo vision is difficult to be used as gives large errors due to the stereo calibration problem (Haseeb et al., 2019). For instance, if a stereo vision-based system is mounted on the front of a train, the distance between the cameras, so-called baseline, is very small compared to the distance from objects at long range; therefore, the errors in triangulating the objects position are greater. Because of this, there has been recently significant work on distance estimation from monocular cameras. In particular, with the emerging use of machine learning in computer vision, there has been significant work on applying machine learning to this problem. For example, machine learning-based method that learns relationship between the distance from the object to the camera and the size of the object bounding box in the camera image is presented by Haseeb et al. (2019).

Active sensors provide their own energy to induce object reflection. In the OD domain, radar, laser scanner and sonar are predominately used. Distance to object is determined with active sensors by measuring the time interval between the emission of the illuminating energy and receiving reflection data, and using this time and the "time of flight" of the energy to calculate the distance, as well as analysis of the receiving signal properties.

Currently, the majority of OD systems use fusion of data from multiple active and passive sensors to increase the overall performances of a system. A comprehensive review of the state of the art of OD systems in air, land (automotive and rail) and water transport industry has been carried out in the SMART project (Banić et al., 2016).

The main difference in requirements between obstacle detection in railways and obstacle detection in other land transport modes, such as automotive, is that long-range obstacle detection is required due to the longer stopping distance of trains among other factors; in water and air transport the operating environment is much different to land transport. Different combinations of sensors, such as stereo vision, mono cameras, thermal cameras, radar and laser were already used in related railway research (Banić et al., 2016); however, the combinations of sensors used to date achieved obstacle detection up to 1000 m. In the context of European railways the target for obstacle detection to support ATO is that it should be able to detect objects (potential obstacles) on and near track up to 2000m ahead of a train, as indicated in the Shift2Rail technical development strategy Shift2Rail ANNUAL WORK PLAN and BUDGET 2019 (Shift2Rail, 2019), because braking distances of railway vehicles can be up to 2000 m.

In contrast to OD, which is related to numerous fields such as automotive and mobile robotics, Track Intrusion Detection (TID) is a term strictly related to guided transport systems, including railways. The purpose of the TID in railways is to detect people or static/dynamic objects that intrude into the trackside environment in order to prevent accidents due to the collision between the guided vehicle and the object. This role, although relevant to the operation of trains, is not directly linked to any single train; TID is, generally, a continuous monitoring process rather than one that only takes place as trains approach, and, therefore, is mostly performed by infrastructure based systems, although the OD systems on trains could also be used to detect intrusions. Currently, the TID are generally only installed on national and international networks at critical elements of railway infrastructure (stations, tunnels, bridges, level crossings, etc.) where the risk of incidents is high to supplement the drivers' ability to detect obstacles and react in time. A common use of TID is on automated urban guided transport systems (metros, skylines) to mitigate the safety concerns regarding the increased of grade of automation (GoA3-4), as there is no driver to prevent collision with hazardous objects, especially passengers. However, the characteristics of urban guided transport systems are generally different to national and international networks in that they are generally closed/protected from external intrusion, and, therefore, the interaction between the guided vehicle and people as well as other objects could be prevented, due to them being in a tunnel, elevated, or the section is short enough to make the use of strong, high fencing practical. Therefore, it is often only the station platforms where intrusion is likely, so installing TID at these locations and detecting intrusion at the main points of entry to the guided vehicle system is likely to be effective at detecting most forms of intrusion. Because of this, most available systems are focused on TID at passenger platforms with a goal to isolate tracks from any passenger's intrusion. Even if platform screen doors seem to be the ultimate solution, in some cases TID can be more suitable mainly due to cost considerations or complexity of migration and infrastructures adaptation (Stephan and Raoul, 2020). However, if ATO on national and international railway networks is considered, where the chances of intrusion are higher and it is not feasible to enclose the entire route to prevent intrusion, then full route, or more extensive TID coverage (not just at critical/high risk locations) might be considered necessary. In the context of rural areas, land used for large domesticated animals (horses, cows, sheep, etc.) is typically isolated from the railway with livestock proof fencing; however, failures due to lack of maintenance and exceptional occurrences (e.g., flooding) may occur, therefore, there is a role for OD, and TID in particular, to play in detecting the intrusion of large livestock onto the railway, and the systems should be capable of detecting such intrusions. In these cases, the types of wildlife not prevented from accessing the railway by livestock fences are generally not a significant threat to the operation of trains. In remote or wilderness areas, the wildlife might be more of a significant threat to trains, mainly due to their relative size. In remote areas, the trackside might be left unfenced or wild animals might be isolated from the track on mainline and freight railways, using isolation fences built along both sides along the track to protect trains from animal activities. Furthermore, tunnels or bridges are in some instances also built to assist and guide animals' seasonal migration where these conflict with railways. Real-time information on animal intrusion (either on unfenced routes, or due to failure of the fencing) is important for the ATO system, so the TID system (as well as the OD system) is critical to protect trains from animal intrusions. Human intrusion is unlikely in either rural or remote areas, but it is desirable to be able to detect it for the protection of life, and the prevention of damage to infrastructure or hazard to trains due to trespass and vandalism. The TID protection system could be a standalone system with human interpretation and decision making regarding the interventions to be made in other systems, however, it is likely to be most effective if connected to the signalling or train control system through vital control/monitoring interfaces allowing automation of the following functions:

- cancelation of movement authority,
- limitation of movement authority,
- emergency braking,
- limiting train speed
- authorisation of platform departure,
- sounding audible warning.

As the OD and TID have similar functions and features, the same sensors used for OD could also be used for TID. Some additional passive and active sensors which could be used for TID are:

- Infrared/laser, based on light interception,
- Weight/sensor panels on the track (Stephan and Raoul, 2020),
- Fibre optic using Fibre Bragg Grating (FBG) sensors.

The interfaces of OD & TID to ATO, ATP and TMS are not currently standardised and discussion of railway industry stakeholders is currently underway how to implement and certify OD & TID in a railway system.

In addition to sensor system features, the communication solutions and their interfaces with the OD & TID system, ATO and the TMS are crucial. For ATO GoA 3-4, wireless reliable communication between trains and the TMS is essential. This is the case even if the system was not to utilise OD, simply assuming the path is clear of obstacles not managed by the TMS (i.e., other trains); however, having OD & TID as components of the ATO makes communication even more critical, particularly as the detection of the object (or intrusion) might be carried out by a detection system not on the train. The communication could be either direct between the OD and the train, between the detection system and the TMS, or a combination. Similarly, the operating principle could be that the obstacle detection systems (onboard and offboard) communicate with the ATO system on the train and the ATO uses the location of the detected object and the information it has about the train (location, speed, path, minimum breaking distance, etc.) to determine the correct train control actions in response to the obstacle (e.g., stop or slow the train). Alternatively, the operating principle could be that the obstacle detection systems (onboard and offboard) communicate with the TMS, which uses the same information to update the movement authority of the ATO, and the ATO implements the correct train control actions in response to the updated movement authority, or some combination of the two operating principles could be used.

In cases where ATO is in operation on lines with ETCS using fixed blocks (ETCS levels 1 and 2, and ETCS level 3 with virtual fixed blocks) and the detected obstacle is further ahead of the train than the current furthest block is authorised to occupy, the TMS could respond by not updating the movement authority to include the block where the obstacle is detected, and the train would stop at the end of the block before the one containing the obstacle. Similarly, in cases where ATO is in operation on lines with ETCS using moving blocks (ETCS level 3 with moving blocks) and the detected obstacle is further ahead of the train than the current furthest extent of the movement authority, the TMS could respond by not extending the movement authority up to a safe distance from where the obstacle is detected, and the train would stop before the obstacle. Where the obstacle detected is within the current movement authority of the train, the train could be instructed to stop immediately by the TMS, depending on the degree of sophistication the severity of the action could be reduced to just the extent necessary to stop the train (or otherwise react) before the obstacle if that is possible. For ETCS levels 2 and 3, the train would be in constant communication with the TMS, for lower levels of ETCS, communication might still be possible and might be considered essential for operating ATO, or another form of communication other than that use for ETCS might be used. Also, an operating principle that uses local decision making to respond to the detection of an obstacle could be used either instead of the TMS or supplementing it.

Regardless of the operating principle for determining or implementing the reacting to the detection of an obstacle of track intrusion, ATO with OD & TID is dependent on reliable communications to function. In addition, all implementations of OD & TID to support ATO (except for closed onboard connections between the onboard OD and ATO) require significant increases in the amount of communication, both in terms of the number of connections and the amount of data. Also, since OD & TID detections are the result of factors outside the control of the TMS, they can occur without warning, therefore, speed of communication and processing of data becomes critical. In any of the operating principles described, the primary function of the OD & TID system is to correctly identify the obstacle location so that the ATO system (including ATO train control and TMS) can determine and implement the correct response to avoid a collision with the obstacle or mitigate the consequences.

4. Overview of Developments on Obstacle Detection and Track Intrusion Detection Systems for Railways

In general terms, the definition of an Obstacle Detection and Track Intrusion (OD & TID) system, in the context of railways, is a technological system to support the operation of trains, which:

- detects obstacles on railway track that might;
  - imped the passage of trains;
  - pose a hazard to trains and, as a consequence (for example of collision with the hazard), hazard passengers, staff and the general public;
- detect intrusions onto the trackside environment of unauthorised persons, animals and objects, which might pose a hazard to trains or be hazarded by the operation of trains.

The aims of an OD & TID system can include (specific aims might vary, depending on the specific implementation):

- Improving safety through improved detection of hazards and threats to trains, passengers, staff and infrastructure;
- Augmenting the detection capabilities of drivers and other human operators, for example as a driver support system;
- Providing automated detections system to support the operation of trains to mitigate the risks of increasing the automation of train operation.

The incentives for developing and implementing an OD & TID system include improvements in safety, operational efficiency and overall cost reduction. In terms of safety, the OD & TID system can overcome some of the limitations of the current conventional detection method, which principally relies on human observations, either by the driver or other operational staff. These limitations (relative to alternative technologies) include: limited reliable detection and identification range, limited detection capabilities in sub-optimal lighting and environmental conditions, and single point of view of driver (susceptible to having line of sight to obstacle blocked), slow sharing, coordination and correlation of detections between different operators and potential inattentiveness or distraction of human operators. In terms of operational efficiency, improved and automated detection by an automated OD & TID system enables the increase in the level of automation of operations, which contributes to the improvement of operational efficiency. Additionally, an automated OD & TID system may reduce the risks of disruptive incidents, mitigate the consequences of unavoidable incidents and improve the response to incidents, making operations more reliable and resilient. Furthermore, in some cases, where the safe operational speed is limited by visibility and other issues related to detection of hazards, OD & TID systems may enable the increasing of the permitted line speed, contributing thus to increasing capacity. In terms of overall cost reduction, both the improvements in operational efficiency and increasing the level of automation of railway operations offer the potential for cost reductions, the expectation being that these savings would be greater than the cost of implementing the OD & TID system and complementary systems.

There are a number of sensing and detection technologies that can potentially be used in an OD & TID system, each with their own capabilities, advantages, and disadvantages. It is estimated that a combination of different sensing and detecting technologies will be needed to provide effective detection coverage. Similarly, there are also a number of ways the system can be implemented and integrated with other operating systems, and the data and information processed and used to support the operation of trains. The selection of technologies, and the implementation and integration the system output to support the operation of trains are complex issues requiring detailed analysis of the requirements for the intended implementation case.

4.1 Detection of Physical Objects on Track

A comparative study on ATO for various operating conditions has been performed within the ASTRail project (ASTRail, 2019) to identify the suitability of several technologies for automated driving strategies at different GoA levels. The analysis considered limited parameters such as static obstacle, moving obstacle, obstacle dimension and obstacle type. The study discusses the feasibility and suitability of applying obstacle detection approach in both railway and other fields to ATO development, however, it was limited to a theoretical level. The study recommended further development of a detection system that would be capable of detecting obstacles lying near the track, which would help with providing the information necessary to determine the distance of the object from the train as early as possible. This would be relevant, in conjunction with the braking distance of the train to the implementation of any mitigation actions in response to the train (e.g., stopping the train). The purpose of the analysis was to identify passive and active sensors to be utilised, therefore, the report summarised in its final recommendations the main candidate technologies: RADAR, Infrared camera, Stereo camera, Omnidirectional camera, LiDAR and Monocular camera. It also identifies multi-sensor data fusion as an approach to improve accuracy, availability and reliability of the sensor system for the function of that sensor system (e.g. obstacle detection) compared with using just one type of sensor. The recommendation is that a multi-sensor data fusion system, which is based on several technologies, could represent the most effective solution for achieving the required railway-specific performances.

One example of a multi-sensory detection system for operating in the railways environment is the ERACLES NEO system, in development by Bombardier (Tannaro, 2020). This system is based on the ODAS solution (Obstacle Detection and Assistance System), which was previously developed by Bombardier and already deployed on some trams, and on ERACLES system for trains, which has environmental perception capabilities of up to 250-350m. The development of both ERACLES and ERACLES NEO systems are part of activities carried out by Bombardier within the Shift2Rail IP5 ARCC project (Automated Rail Cargo Consortium: Rail freight automation research activities to boost levels of quality, efficiency and cost effectiveness in all areas of rail freight operations).

The ERACLES NEO system is designed primarily for obstacle detection with regard to local train control (i.e., on-train decision making and control) and uses a combination of stereo visual light cameras, infra-red light cameras and radar, along with fusion of data from the sensors, to detect obstacle and sense the environment from 0m in front of a train up to 1000m (radar up to 150m, stereo visual up to 250-350m). In addition to detecting obstacles, the environment sensing capabilities of this system include classification of objects using AI, switch and signal detection, and route detection (path of track the train is following). The scope of the ERACLES NEO solution and its predecessors has some similarities with that of the system proposed by SMART2 (see §4.5), and there are potential synergies between the technologies. However, ERACLES NEO is mainly focused on observation from the front of the train and local train control, whereas SMART2 is focussed on detection and classification of obstacles at longer ranges, of up to 2km ahead of trains, including from the front of the train and the trackside, but not the train control response. The development process has identified some key non-technical issues and benefits relating to development and implementation, which would need to be balanced. These include the long-term development and testing process required, liability and acceptance issues, the potential reliability issues in the short-term on introduction, and expected improvement in overall system performance, reliability and LCC in the long-term.

Significant research on OD in railways was also carried out within the Shift2Rail project Smart Automation of Rail Transport (SMART) (SMART, 2019), which is the predecessor project to SMART2 project. The main concept in development of SMART OD was that an on-board system should work efficiently for the freight trains running on mixed mainlines at 80 km/h, with existing infrastructure, and in all weather and illumination conditions.

SMART OD system is based on a combination of different vision technologies: thermal camera, night vision sensor (camera augmented with image intensifier), multi RGB cameras, and laser scanner (LiDAR).

All SMART OD sensors, together with the network and power components, were integrated into a custom designed sensors' housing as shown in Figure 4 (top). The sensors' housing serves to both easy mounting/dismounting of the sensory OD system to/from the test vehicle and the protection of the sensors due to a protective glass and special germanium glass for the thermal camera (Figure 4 middle).

The SMART projector demonstrator aimed to meet the different ***functional requirements*** for the OD system, as follows:

- Frontal obstacle detection: Detect objects, potential obstacles, on the rail tracks and near the rail tracks ahead of the locomotive. Targeted potential obstacle was every object found on or near the rail tracks that is not the part of the railway infrastructure.
- On-board obstacle detection system: to integrate OD system into housing, which could be easily mount/dismount onto/from the frontal profile of the locomotive so to enable sensor-based perception of the scene ahead of the locomotive.
- Robust system resistant to environmental conditions: OD system housing protects sensor from environmental conditions such as dust, mud, rain.
- Long-range obstacle detection: to detect obstacles up to 1000m ahead of the vehicle.
- Rail track detection: to recognise the rail tracks ahead of the vehicle (ahead of the ODS mounted on the vehicle), to define region of interest for detection of obstacles.

- Sensor Fusion: OD system has the flexibility to choose and integrate different sensors so that resulting information has less uncertainty than when using individual sensors.
- Communication and HMI: to provide the sensor data to be visualised on Human-Machine Interface (HMI).

Figure 4: (top) Sensors' housing of the integrated SMART OD system demonstrator with the integrated sensors labelled. (middle) CAD model of the closed sensors' housing with protective glass labelled. (bottom) Frontal profile of a SMART test vehicle, Serbia Cargo ŽS series 441, with the OD system demonstrator mounted under the headlights (Ristić-Durrant et al., 2019)

- Data to be displayed: live image from the selected vision sensor with highlighting of detected objects overlaid on the image, as well as the distance to detected objects.
- Software implementation: the OD system has software installed which enables off-line work with sensor data recorded in real-world experiments in addition to online processing of sensor data.
- Object classification: The obstacle detection system is capable of classifying the objects belonging to different classes, such as humans, bicycles, vehicles, and some types of animals. For improving safety in railway applications, it is of high interest to enable detection of other common obstacles such as fallen trees and rocks.

Figure 5 to Figure 9 provide some of the example results of SMART OD system processing, showing mid to long range detection of obstacles in different environmental and lighting conditions, with different sensors, as well as object classification necessary for a railway OD system.

Figure 5: Object detection and distance estimation in RGB camera image recorded in winter (snow) environmental conditions; Ground truth distance: 835 m (distance estimation error for person 1 and person 2 was 0.97 % and 1.74% respectively) (SMART, 2019)

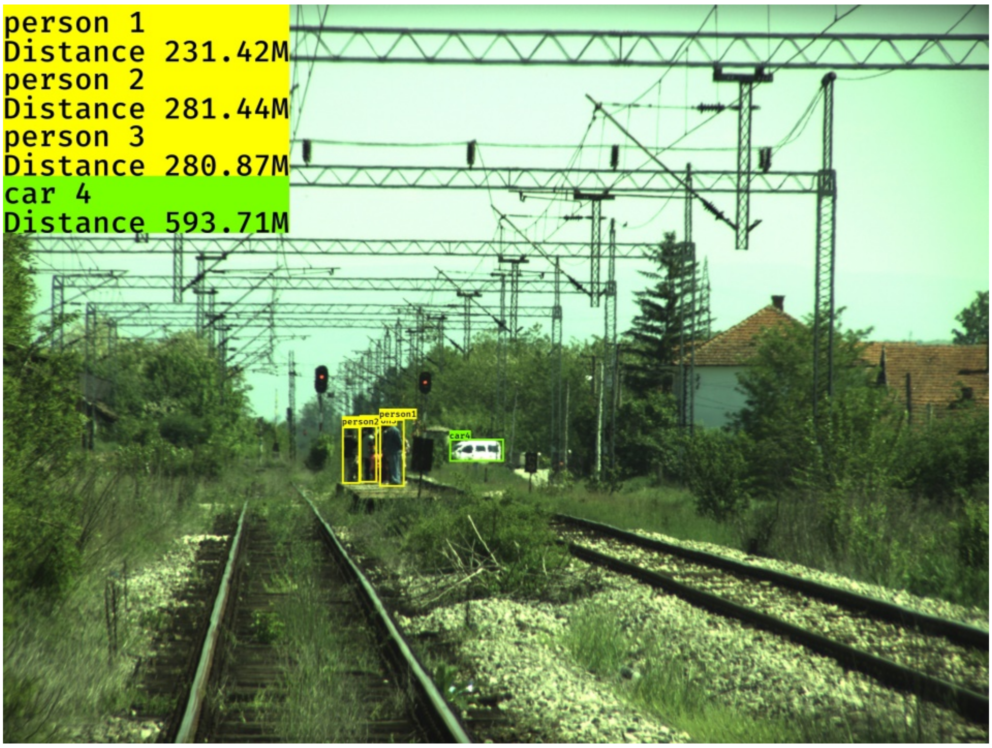

Figure 6: Object detection and distance estimation in on-board RGB camera image; Ground truth distance: for persons (station middle point) 266.69 m (average error 8.32%), for the car 597.87 m (error 0.69%) (SMART, 2019)

Figure 7: Object detection and distance estimation in on-board thermal camera image recorded in environmental condition of 38°C; Good detection result despite low-contrast image; Ground truth distance for person: 155 m (error 0.025 %) (SMART, 2019)

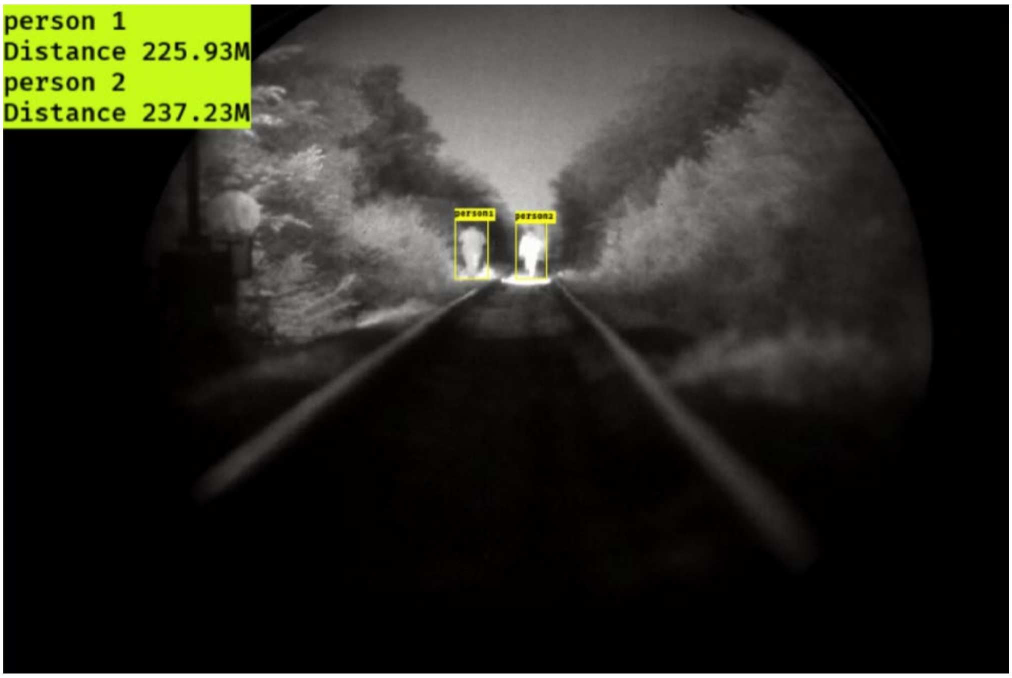

Figure 8: Object detection and distance estimation in night vision camera images recorded in night (poor) lighting conditions. Ground truth distance: 225 m (error for person 1 and person 2 was 0.41 % and 5.43% respectively) (SMART, 2019)

Figure 9: Object classification in real-world scene: persons and an animal (horse) are crossing the rail tracks on unsecured crossing while train is approching; Person on the motorbike is "waiting" on the left side of the rail tracks crossing and a car is parked on the left side of the rail tracks (SMART, 2019)

4.2 Detection of Moving Obstacles at Stations, Level Crossing, Yards or Other Special Area during Shunting and Other Specific Operations

To improve the hindered automation of freight rail and ensure the safety of train operation, the development of a safe and reliable on-board obstacle detection system for railways was included in the Shift2Rail Multi-Annual Action Plan-(MAAP), Shift2Rail (2015).

Based on past surveys, most accidents in rail environment happened in stations, yards and level crossing areas (Pu et al., 2014), especially at railway level crossings where vehicles and people cross the track and could make mistakes in observing the traffic signal, or take risks ignoring the signal or barrier. In recent years, safety issues at level crossing areas have been carefully considered in countries across Europe. For example, from 2010, Network Rail, the British rail infrastructure manager, started a landmark level crossing risk reduction programme, which closed level crossing built more than 180 years ago and upgraded level crossing areas with a group of sensors linked to the network to assist automatic gates, warning lights and barriers. British local stakeholders are in charge of monitoring the usage of a level crossing to indicate its risk level, availability in daily operation and cost of closure (Network Rail, 2010).

To avoid collisions at level crossings, the detection of the vehicle or the people should be done at the earliest possible opportunity. However, there is always the risk that people do not respect signalling or that an unexpected event results in the unwanted presence of people, vehicles, or goods in the train's passageway. CCTV systems are often used to allow remote operators to identify these situations and react promptly. Despite the advantages of relying on human-based decision making, the high number of trains and level crossings to control posit this strategy error-prone. Thus, it is preferable to have the human acting as a complement to sensor-based automated solutions. In yards, the areas where persons or vehicles could cross the tracks might be less well defined, have less or no signalling for pedestrian or road vehicle traffic, cover larger areas, or have a combination of these factors in comparisons with the mainline; in the meantime, it is also expected that only authorised persons or vehicles are using the crossings and the train speed is lower. In situations such as unmanned level crossing on the mainline, or in yards, the train travelling at any speed, fitted with an obstacle detection system could be able to detect the static or moving object (including persons and vehicles) and pass this detection to the ATO for it to make a decision to slow or stop the train, or sound the audible warning device.

Various electronic devices have been developed for the detection of obstacles; the detection devices and systems used for railway applications related to train control and safety of train operations need to be satisfy the standard specifications according to EN 50129:2018 (CENELEC, 2018). Electronic devices such as tilting 2D laser scanner (Amaral et al., 2016) have been used to detect large obstacles but find it difficult to detect small obstacles. Two studies for the detection of obstacles were performed considering different types of level crossing in the Britain and automated obstacle detection (Robinson, 2015; Dent and Marinov, 2019); it was found that automated obstacle detection could be helpful to improve safety, reduce cost and also lower down the waiting times for the road vehicles and pedestrians in level crossing area. The relevant electronic devices that have been identified for these use cases include CCTV, LiDAR, RADAR, Infrared Thermal Imaging, Ultrasonic Sensors, and Induction Loops. There must be the complete interlocking of the various devices with the automated system as per EN 50129:2018 (CENELEC, 2018). Furthermore, it was recommended to complete the automation of full barrier crossing, but at half barrier crossings there would always be the chance of heavy train braking due to the need to react to road vehicles and pedestrians zigzagging between the barriers. With the development of new electronics, devices are getting cheaper, and level crossings and yards could be fitted with them. The recorded data from the electronic devices could be used to train a neural network (Yu et al., 2018) to accurately detect obstacles. Tang (2015) proposed a systematic approach for obstacle detection in station areas, using virtual instruments technology and image processing technology to assist laser sensors and increasing the efficiency of detection system. The system ensures the safety of a train when it is approaching a platform and would enable it to detect and avoid collisions with obstacles falling from the platform.

A previous S2R project, OPTIYARD (Optimised Real-Time Yard and Network Management), reported in Deliverable D3.2 (OPTIYARD, 2018) the development of a decision-support software for real-time yard management, including interaction with surrounding network of a yard area and ad-hoc timetable planning to optimise yard operation, which was simulated. The optimisation module and algorithms have been proven for large and complex freight transport networks, and integrated well with IP5 activities towards automation, e.g. intelligent assets and automated shunting and mainline operations. OPTIYARD has also directly supported projects S2R-CFM-IP5-02-2015 (Start-up activities for Freight Automation) and S2R-OC-IP5-01-2015 (Freight automation on lines and in yards). It can be foreseen that automation of the logistics elements of yard operations (to determine the required train movements), and development of detection systems to ensure the safety of automated train movements in yards, would be enablers of implementing automated train operation in yards.

To provide a TMS with the necessary detection functionality for ATO, a sensor system on-board the vehicles should provide sufficient information of obstacles in front of the train. This will require robust telecommunication, data and radio network; therefore, the existing interface and data exchange infrastructure are a capability bottleneck that should be determined and resolved at the same pace as the development of the obstacle detection system. In recent ATO project between THALES and Albtal Transport, sensors with different parameters have been selected to detect objectives in short-range, mid-range and long-range, and determine appropriate braking curve which resulted in an ATO system with GoA3. Due to the complexity of potential circumstances on the mainline railway, it is difficult to find a balance between safety and availability, in comparison to existing ATO systems such as metro lines or airport express lines, which, usually, are designed as a closed environment, with limited scenarios to be considered (Briginshaw, 2019). From 2016, ATO is considered into the Control Command and Signalling System (CCS) TSI, to ensure the interoperability of ATO supported vehicles. The challenges mainly include (Stacy, 2017):

- The standardisation of trackside information from TMS;

- Functional specification for the ETCS on board interfaces;
- Determining human factors, release speed, audible and visual warnings;
- Interfaces between ATO and ETCS for freight operation;
- ATO requirements for driverless and unattended train operation

All the above have been partly addressed by the Shift2Rail projects X2RAIL-1, X2RAIL-4 and ASTRail.

4.3 Track Intrusion Detection and Intrusion Detection Systems (IDS)

Intrusion detection systems mainly focus on the detection of people, vehicles, or their movable objective accessing or loitering in unauthorised areas around railway track and stations. This is the main focus of the Track Intrusion Detection systems considered within the SMART2 project; however brief mention is also made at the end of this sub-section with regard to the related field of system intrusion detection, which also requires detection of unauthorised physical access to restricted areas.

The application of intrusion detection or remote sensing technologies would serve to improve the safety of the rail passengers and road users, as well as protect the general population. It would also enable a reduction in the risks to the general population and the environment from shipments of hazardous substances, and aid in the prevention of disruption and relief of congestion by reducing the number of incidents and delays due to intrusion incidents. The reasons for intrusions onto the track or into the railway environment vary, and they could be, e.g.:

- accidental/unintentional, such as a result of a road traffic collision on an adjacent road, or a passenger falling from a platform at a station;
- accidental intrusion of rail vehicles onto a section of track due to, derailment from an adjacent track, run-away, or unauthorised movement;
- deliberate, such a trespass for the purposes of theft or vandalism of with railway equipment or cargo;
- deliberate, such as trespass for the purposes of using the railway as an unauthorised access route;
- deliberate, such as interference with railway equipment with the intention of causing a security breach, initiating an accident or other incident, or terrorism related.

In all of these cases, the intrusion onto the track or trackside environment can result in hazards to persons (both authorised persons, such as staff and passengers, and unauthorised persons such as intruders) and property (mainly railway equipment, vehicles, infrastructure etc.), which are undesirable. Therefore, it is important to detect these physical intrusions into the restricted parts of the railway environment, to ensure that trains can be operated safely without being at risk from intrusion onto the track, and to reduce the risk to those intruding onto the railway. Besides the operational objectives of detecting physical intrusions into the railway environment, it is also advantageous to detect them from the point of view of general safety and security of assets. The automated detection of intrusion into the railway environment is of some value as a driver aid to alert them to possible hazards, so they can respond in a timely manner and reduce the risk from the incident, but it is of significant value as a part of ATO. For ATO, TID systems can replace and improve upon driver and other staff observation of the railway network for hazards to mitigate the risks of ATO, particularly unattended ATO, related to undetected intrusions onto the track.

An ever-increasing demand for improved security, especially within the transport sector, has led to a significant amount of worldwide research on intrusion detection sensing systems. Specifically, intrusion sensing systems for railway environments have been proposed to protect railway tunnels, level crossings and train depots from theft and vandalism, which would result in significant cost savings. A relevant study about the various technologies has been done to identify potential methods and review the state of the art of various types of detection of intrusion and obstacle (Baron and DaSilva, 2007). Another study explored the implementation of an intrusion sensing system combining Fiber Bragg gratings (FBG) sensors and FBG accelerometers from micron optics to protect large areas of the railway, such as tunnels and stations, from unauthorised activities (Catalano et al., 2014). Usually, the intrusion detection systems are based on conventional technologies including microwave sensors, electric field sensors, ported coaxial cables and infrared sensors, which assist human staff. However, conventional technologies can be affected by electromagnetic interferences associated with the movement of a train, which are inevitable. As a result, FBGs was considered to be a promising approach that may overcome some of the disadvantages of traditional technologies and could provide high sensitivity and stability in harsh environments.

Komalachitra et al. (2017) proposed a detection system based on hybrid technology and image processing, which was designed to continuously monitor and use a warning system to ensure the safety of trains around station areas, without the need of stopping a running train. The technology comprises a camera mounted in the train station, which monitors humans' movements, and, once unauthorised movement is captured, the system will send an alert to the train driver to warn them about the obstacle. This article also discussed a hybrid approach to power the whole system with renewable energy, which would minimise the use of by-products within the system and switch-off unnecessary sensors as much as possible.

Super resolution radar techniques with stepped multiple frequency radar are also considered potential solutions to monitor the safety issues around a railway platform, as these could provide higher resolution performance, according to an experimental study based on a software defined radar (Ukai et al., 2011). The parameters of stepped multiple frequency have been uniquely designed and the signal processing is achieved by applying A/Ds and D/As of high-sampling rate within an inclusive designed FPGA board. The proposed approach allows monitoring in larger distance and wider angle.

Another study (Xie and Qin, 2019) reports a multi sensor fusion method and technology that was used to detect the intrusion with help of training data fusion algorithms to increase the accuracy of the detection system. The computational results have shown that using AI and Internet of things (IoT) may be a feasible solution to improve the accuracy and effectiveness in all-weather condition.

A significant proportion of the TID systems developed have focused on detecting intrusions in the area of stations, in particular of passengers intruding onto the track from the platform, since this is an area where there is a risk of trackside intrusion, and, in the case of metro lines enclosed in tunnels or otherwise isolated from the surrounding, the main potential point of intrusion. However, for national and international railway networks, the expansive nature of the railway infrastructure makes it extremely vulnerable to undetected intrusion, and over these large areas, other technologies, or adaptions of these intrusion detection technologies might be more appropriate.

With regard to the related field of system intrusion detection, the S2R project CYRail has identified and discussed the requirement for the intrusion detection system (IDS) (Alexe et al., 2017). Technical tools for detecting and alerting users about information threats should be provided; furthermore, the following information should be registered:

- Information on anomalies of the network traffic under detection;
- Type, date and time of detected threats;
- IP addresses of the source and object of the threats;
- Port number of the source and object of the threats;
- Priority level of detected threats.

The above requirements are restricted to the instruments connected by internet network but the physical intrusions on the track side are also to be detected as earliest as possible opportunity in order to take the necessary action. There may be various ways to intrude into the control system, including manipulation of trackside instrument and infrastructure, accessing signalling equipment or hardwired communication lines, accessing through wireless communications, and accessing through communications traffic carried over the internet.

4.4 Detection of Other Phenomena and Conditions Affecting Rail Operation

Train operation could be also affected by natural phenomena that could impact on track condition and/or vehicle-track interaction, such as accumulated flood or standing water, snow or hailstone and seasonal fallen leaves on the track. Although these cases are not physical obstacles on, or near the track, they require specific detection and mitigation solutions that may be relevant to those required in the case of proper obstacles on the track or track intrusion. Therefore, these particular nature-caused phenomena affecting train operation are briefly reviewed and presented in this sub-section, along with techniques used to tackle them.

The affected areas can be broadly divided into different categories, as proposed, e.g., in (Robinson, 2015), (Thommesen et al., 2014) and (Ishizaka et al., 2017):

- Runoff from higher topography - areas of greatest flood depths, which tend to be at the base of the steeper land;
- Localised surface water runoff – where the surface water flooding tends to be a result of localised ponding of surface water;
- Sewer Flooding – areas where extensive and deep surface water flooding is likely to be the influenced by sewer flooding, where the sewer network has reached capacity and surcharged;
- Low Lying Areas - areas such as underpasses, subways and lowered roads beneath railway lines, which are more susceptible to surface water flooding;
- Railway Cuttings – e.g., stretches of mainline railway track (in cuttings) are susceptible to surface water flooding and;
- Railway Embankments - discrete surface water flooding locations along the up-stream side of the raised embankments where water flows are interrupted, and ponding can occur.
- Snow or hailstones on the track – due to weather changes and extreme condition, rail-wheel adhesion degrades to lower value which causes delays and problems with train timetable and risks of wheel slipping when deceleration and braking;
- Seasonal fallen leaves and snow-covered vegetation on the track - the leaves stick to the rail surface and form a thin film which could degrade rail-wheel adhesion and affect unexpected problems on train operation;
- Ice formation at tunnel entrance – when the ice occurs in the fracture network close to the tunnel contour or in the interface between the rock and shotcrete, it can cause fallouts in both materials, so ice formation can obstruct train passages and cause time delays.

Most of the weather-related notifications could be received from the weather reports; however, for a line that is mainly high-speed/high-capacity (HS/HC), water stagnant over the track should be detected specifically. For the identification of stagnant water, a remote sensing methodology for estimating standing water using the Moderate Resolution Imaging Spectroradiometer (MODIS), an optical sensor with a spatial resolution (pixel size) of 250 to 500 meters has been proposed in (Guerschman et al., 2011). A complete risk analysis has been performed for flood water and damage quantification to the railway infrastructure on the French Railway network and an innovative approach based on Geographic Information System (GIS) (Cheetham et al., 2016) model to identify zones of the railway network at risk of different types of flooding. To cater such situation, a train running with ATO facility has to be capable to read out the detection results from the GIS, or odometry sensors and make possible decision and communicate to the ETCS for the safe stopping of the train. There is a need of models that allow the evaluation of flood risk and damage of tracks to be undertaken at different scales and aid in targeting precise reaches of railway line to be studied in more detail. It is a tool which can aid in the management of flood risk on the railway network, optimising for example the maintenance program of drainage structures, ensuring monitoring and inspections are targeted at problem reaches, identifying areas where civil works are necessary and improving the overall resilience of the railway system.

Furthermore, there have been many methods developed and proposed, including, e.g., vegetation management along the track/infrastructure, as well as more technical methods such as sanders, Wheel Slide Protection systems, Magnetic track brakes, or Eddy current brakes. It has been found that all the above methods have drawbacks and a proper technique must be devised to cater natural phenomena causing low-adhesion issues. A potential solution is to improve the data-feed to the Autonomous Train Operation (ATO) with all the information about the best possible decision for slowing down the vehicle or using WPS. To support a sophisticated decision support system, a novel obstacle detection is a must for the autonomous operation of the cargo haul. Such obstacle detection system shall be integrated into the ATO module and it shall include multi-sensory system to provide fail safe and reliable obstacle detection at short (up to 20 m) and long range (up to 1000 m) during day and night operation, as well as operation during impaired visibility (such as in the case of fog and bad weather condition) (Ristic-Durrant et al., 2016).

4.5 Concept of SMART2 Holistic System for OD & TID

The SMART2 project builds upon the results achieved in the SMART project, by advancement, innovation and development of the SMART2 on-board long-range all-weather OD and TID system. An overview of OD & TID system concept proposed to be developed in SMART2 is shown in Figure 10. The SMART2 project will study operation conditions of trains in general and freight trains in particular, and propose a prototype OD & TID system to assist real-time train operation. SMART2 OD & TID system will consist of three sub-systems: the on-board, airborne and trackside OD & TID sub-systems. All three sub-systems will be integrated into a holistic OD & TID system with interfaces to a central Decision Support System (DSS), which will have the role to manage the OD & TID system according to the different operational and environmental conditions and potential hazards.

Therefore, the SMART2 project focuses on:

- The improvement of the on-board OD & TID system developed by S2R SMART project as a sub-system;
- The development of new trackside and airborne OD & TID sub-systems;
- The integration of all sub-systems into a holistic OD & TID system.

The target for the distance ahead of a train for the OD & TID system to detect dangerous objects on, or approaching the train's path is 2000m. The approach adopted in SMART2 to achieve this, is to improve the on-board train passive and active detection systems developed in the S2R SMART project (particularly with regard to detection capabilities at long range), and use fusion of data from the on-board, trackside and airborne sub-systems to further increase detection coverage and accuracy.

The approach proposed for the trackside OD & TID sub-system to be developed in SMART2 mainly focuses on the detection of obstacles and track intrusions at level crossings, where there is a high risk of obstacles and intrusions, using a laser optics system, which would be integrated into the holistic SMART2 OD & TID system.

The approach for the airborne sub-system is to equip a commercial drone with detection systems and integrate the control of the drone with the DSS, so that the drone can be deployed in a variety of operational modes (e.g., regular patrol, scan specific area, etc.) to detect hazards along the route, particularly where the coverage of other sub-system is less than complete.

The overall concept of the SMART2 OD & TID system, and the approaches adopted for each sub-system, as well as the integration of the sub-systems, will be investigated in detail as the technical development in the project progresses and the development outcomes and results will be reported in future deliverables.

Figure 10: Concept of SMART2 holistic system for OD& TID consisting of on-board, trackside and drone-based OD& TID sub-systems, interfacing with central DSS unit

A holistic approach to autonomous obstacle detection for railways using the input from multiple sensor sub-systems would enable the detection area ahead of the train to be increased in many situations, compared to systems solely mounted on the front of the train. This includes situations where line of sight from the front of the train to areas behind a curve, slope, tunnels and other elements is blocked, as well as increasing the effective detection range ahead of the train in all situations, including on long straight tracks. The data recorded by the sensors of each of three OD & TDI systems (on-board, trackside and airborne) will be processed, and can be used to inform DSS about possible obstacles and track intrusions in their fields of view, as well as the ATO/TM system. DSS will integrate and process the information coming from the three OD & TID sub-systems (e.g., classification of the detected object or intrusion, determination of its location, etc.) and will make decisions concerning the OD &TID system control and management actions required (e.g., directing sensors and vectoring airborne sub-system units). The output of SMART2 system on detection, location and classification information regarding detected objects and intrusions could be sent to

ATO and/or TM system, which will determine and implement the appropriate train control response. SMART2 platform will be flexible and open for interfacing additional OD & TID modules based on existing and future technologies.

For the development of on-board OD sub-system prototype, SMART2 envisages multi-sensory on-board system integrated in a custom-made housing that protects the sensors, holds them in the correct alignment and enables easy mounting/dismounting of the unit to/from a locomotive. A demountable unit removed the need for modification of the locomotive and enables it to be set up for different evaluation tests in static and moving conditions, and on different compatible/adaptable vehicles. The multi-sensor SMART2 on-board system will consist of different vision sensors enabling obstacle detection under daytime and night-time illumination conditions. The RGB cameras and thermal camera will be accompanied with a novel vision unit LADAR (LAser Detection Active Ranging), to be developed in SMART2 project, based on Short Wave InfraRed (SWIR) vision technology and range gating. The addition of this novel vision sensor to augment the capabilities of the RGB and thermal cameras will significantly increase the performance of the on-board OD & TID system, improving the functional reliability in different illumination and weather conditions, including challenging weather conditions. The performance of the on-board system will be also advanced (relative to the achievements of the SMART project) by mounting the cameras in a gimbal to allow their rotation, so that the cameras orientation can be controlled and their field of view directed to the track ahead of the train, particularly when the track is not directly ahead of the train, such as in curves and at junctions. As part of the gimbal control for the SMART2 cameras, a range sensor, such as radar detection system, will be used to determine the angular relationship between the front of the train and any object on the track. This radar information will be a set-point for the gimbal control module to orient the camera in direction of detected object. Vision software will then perform object classification and object distance estimation based on the images and orientation of the cameras, and the range sensor.

The SMART2 airborne sub-system demonstrator will consist of a nested Unmanned Arial Vehicle (UAV) (drone), which will be placed on a pillar next to the rail track at strategic locations such as tight curves, gorges or landslide prone locations. The concept of SMART2 stationary airborne (drone) based OD & TID system is illustrated in Figure 11. The drone's nest will have an automatic charging station, hardware for hosting processing algorithms for OD & TID, and a communication station with two sub-modules, one for the communication between the drone and processing hardware and the second one for the communication between the drone-based OD & TID system and the DSS. The UAV (drone) will carry appropriate vision sensors, RGB camera and/or a thermal camera with a variable focal length lens. If two sensors will be used in demonstrator, one of the vision sensors could be replaced with a range sensor such as LiDAR. The final sensor equipment will be decided during the requirements and specification phase of the project. In general, the drone will be a flexible OD & TID asset with a number of different operational modes, including charging mode(s) where the drone is docked with the charging station (with or without sending sensor data from its charging location), and active modes where the drone will be airborne and fly as directed by the DSS, sending sensor data back to the processing hardware at the charging station, from where the processed data is sent to the DSS.

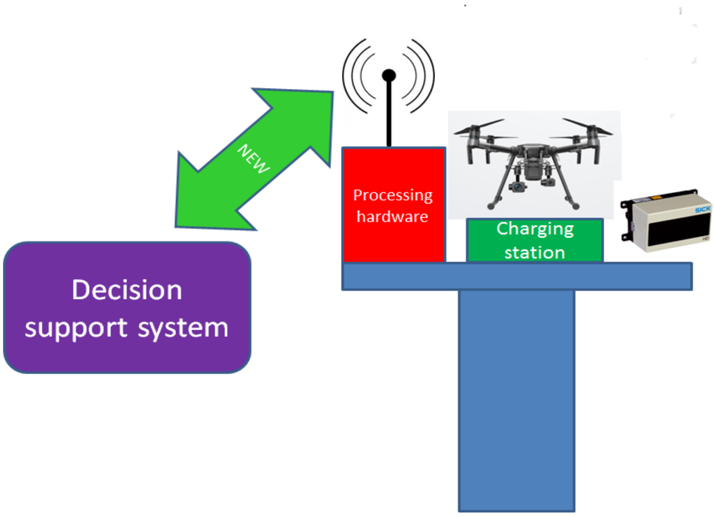

Figure 11: Concept of SMART2 airborne OD & TID sub-system

The interfaces and functionality of the drone, processing and data transmission will be investigated during the forthcoming technical phases of the project. In the active modes, upon the command issued by the DSS, the drone will leave the charging station and will investigate a section of track and its surroundings as specified by the DSS. These active modes could include a regular patrol mode where a drone is dispatched by the DSS periodically to patrol a pre-determined flightpath along the railway route to check for obstacles or intrusions, or a specific area or target mode where an area of interest is identified, for example a track intrusion detected by a trackside sub-system at a level crossing, and the drone is dispatched to investigate. The triggers for a drone flight could be on a schedule basis (possibly coordinated with the train timetable) or in response to specific inputs, such as an obstacle or track intrusion detected by another sub-system, specific conditions such as adverse weather increasing the risk of fallen trees, landslides or flooding, on request from a human operator or supervisor, or in response to an emergency situation.

The key component of the trackside OD & TID sub-system will be an advanced 3D laser optic subsystem. This subsystem will enable optimization of the operational parameters of the OD & TID system (detection range, scanning angles, scanning resolution, scanning frequency). This type of trackside sub-system to be developed within the scope of the SMART2 project is intended for OD & TID at level crossings; other potential applications for this trackside detection technology include implementation where tracks pass alongside platforms, or where bridges pass over tracks, where there is an increased risk of objects or persons falling onto the track. In addition, other types of trackside OD & TID sub-systems could be developed and integrated in the future, using the integration of the laser scanner system to be implemented in theSMART2 prototype as a benchmark and example. An example of such a type of trackside sub-system would be static, but directable, camera “watch towers”, using the vision-based optical components and detection algorithms utilised in the on-board and airborne sub-systems, located at curves, tunnel entrances and other obstacles to the onboard sub-systems line of sight, to provide detection coverage ahead of the train.

The type, location, and functionalities of the trackside OD & TID sub-system elements may be specified for different purposes and according to an assessment of the risk and detection coverage required, or in order to provide full coverage. For example, OD & TID around level crossing mainly monitors the movements of road vehicles and pedestrians and protects the running train from intrusion of vehicles and pedestrians when trains approach, as well as protecting the users of road vehicles and pedestrians from trains, as far as possible, should they intrude on the trackside area. In station areas, the OD & TID mainly focuses on the monitoring of dynamic objects and passengers and report detection of any person falling from a platform, or object falling from platform that is potentially damaging to the train (or risks its occupants as a consequence). The locations of the trackside OD & TID system should be decided based on studies of a railway route, considering the overall coverage of the OD & TID system required, factors which hinder the detection capabilities or operation of the onboard or airborne sub-systems, an analysis of the potential hazards, the level of risk considered acceptable, the mode of train operation (i.e., driver or ATO, along with the GoA) and the resources available. It is anticipated that, typically, a trackside OD & TID device of appropriate type will be placed alongside the track at designated intervals or as necessary to provide the required level of coverage, and to cover specific areas such as level crossing, platform, bridges, etc. where more intensive coverage is determined to be necessary.

SMART2 OD& TID sub-systems will interface through the central DSS. Each sub-system will locally perform sensor-based object detection and classification as well as estimation of distance between the detected object (potential obstacle) and the sub-systems sensors. The sub-systems processing results will be sent to DSS as illustrated in Figure 12. The blocks framed by a blue rectangle in Figure 12 illustrate the activities/tasks within the scope of the SMART2 project, and the interfaces between different systems and sub-systems are shown in different colours.

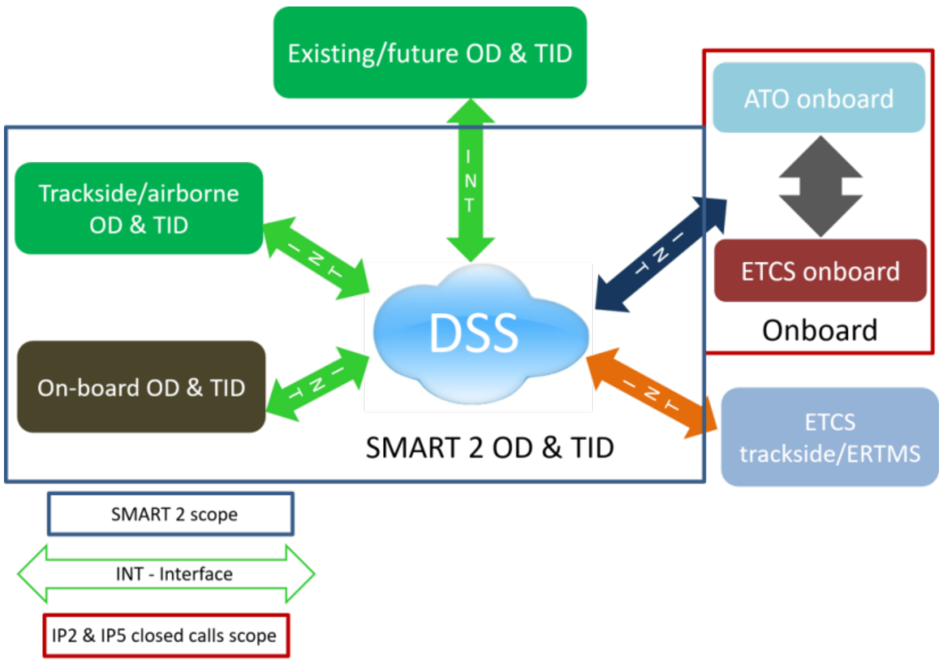

Figure 12: Concept of SMART2 integrated OD & TID system architecture

The interfaces marked with green denote the interfaces to be developed in SMART2, and represent the communication between the sub-systems' processing units and the DSS, which mainly consists of the three OD & TID sub-systems sending the locally obtained processing results to the DSS (with OD & TID sub-system management and control data being sent the other way). The interface marked with dark blue illustrates intended connection between the SMART2 DSS and the train in order for the SMART2 DSS to gather train related data such as the position and speed of the train. Also, this train interface could be used for SMART2 DSS to report OD & TID processing results to ETCS onboard/ATO onboard, for the onboard train control to respond to according to a ruleset determined outside of SMART2. The interface marked with orange colour illustrates the intended connection to the traffic management command centre, and is to be used by SMART2 DSS, on one side, to gather data about trains in the area, such as the direction and path of the trains and possibly data related to authorized persons which might be in the detection area legitimately. On the other side, this connection could be used to send processed OD & TID data to the traffic management system (ETCS trackside/ERTMS). The precise specification or architecture of the interfaces between the SMART2 OD & TID system and the onboard and trackside systems for train control and traffic management, or indeed the precise architecture and mechanisms for applying OD & TID in ATO, have yet to be determined. Based on the analysis of freight specific use-cases of OD & TID in the context of ATO, and inputs received from the IP2 and IP5, SMART2 will determine the OD & TID system requirements, in terms of the detection data to be output by the system, and the train and TMS input data it would require. The scope of SMART2 is to develop and demonstrate the OD & TID detection technologies to provide reliable OD & TID in the area ahead of trains up to a range of 2km. The architecture of the interfaces with the train control and traffic management systems, would be determined in the future when the architecture of the ATO with OD & TID is defined.

The SMART2 DSS will be implemented in cloud environment using a 3-layer architecture, consisting of a presentation layer (GUI), application layer and data layer. An illustration of the intended architecture is shown in Figure 13. The precise architecture design, including the specifications for each individual block will be determined in further development work and will be reported in deliverable D1.2.

The blocks with blue background in Figure 13 represent SMART2 modules that will be specified, developed and validated (TRL6/7) during the project lifetime. The blocks with orange background represent SMART2 modules that will be only specified during any future implementation of the project outcomes. The "SMART2 data storage" module will gather all data collected from the development and demonstration implementation of the system during the project, and in a full future implementation of the system would gather all the detection data for the OD & TID system. The "External data" module would enable the integration and interfacing of OD & TID systems with route knowledge and route settings from the infrastructure management systems. This connection involves receiving all data gathered in TMS control centre from different sources regarding the position of the detection systems, location and route of the tracks and signals, status of the relevant infrastructure. The outputs of the DSS, which could be connected via interfaces to train control and traffic management systems in future integration of OD & TID system with ATO, would be the processed detection results for the system. The decision-making modules of DSS will run in cloud environment and will exchange high-level data with on-board and trackside/airborne OD & TID systems by means of uniform interfaces as the processing of raw data (e.g., images) is performed locally by subsystems responsible for sensory information.

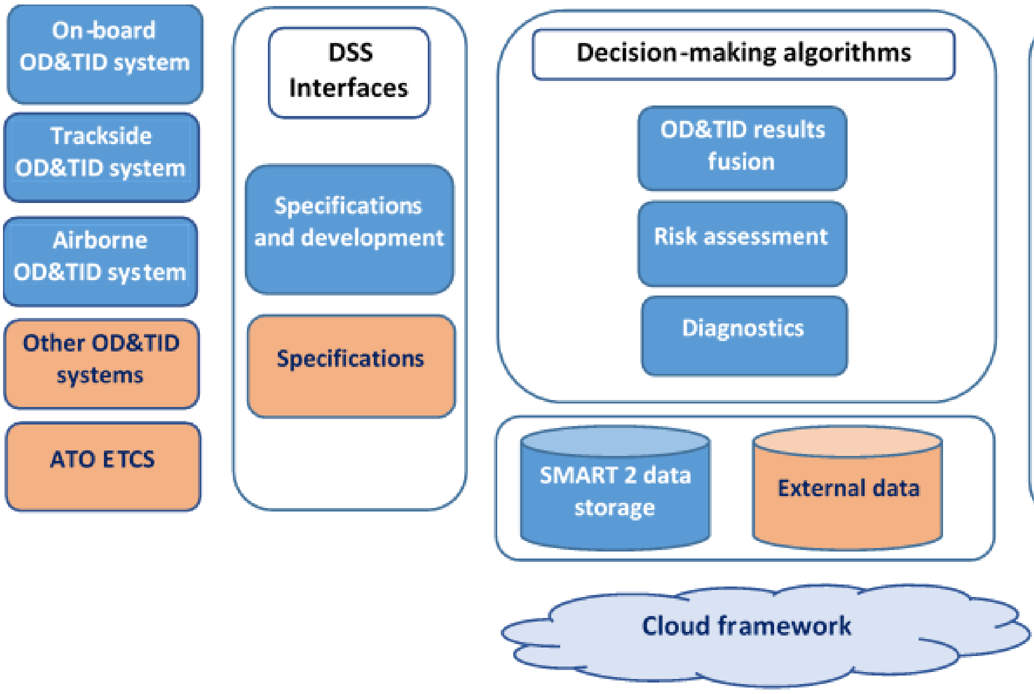

Figure 13: SMART2 DSS 3-layer architecture

5. Use Cases for Obstacle Detection and Track Intrusion Detection Systems

5.1 Introduction to Use Cases for Obstacle Detection and Track Intrusion Detection Systems

This section presents the relevant use cases (UC) that have been identified and analysed by the SMART2 consortium in relation to further development of the Obstacle Detection and Track Intrusion Detection (OD & TID) system, which is the scope of the project.

Potential use cases for Obstacle Detection and Track Intrusion Detection (OD & TID) systems have been identified and analysed. The analysis and subsequent description of each use case has considered inputs received from stakeholders, particularly from those involved in Shift2Rail IP5. The main inputs have been received at a face-to-face meeting between the SMART2 consortium and S2R IP5 members: SBB, DB Cargo, DB Netz and Bombardier.

Consideration has been given to the potential use cases for OD & TID system identified by Swiss Federal Railways (SBB) (Nolte and Napoli, 2020), where the object detection and recognition/classification technologies, as well as technologies to determine the hazard level of/to the detected object, could be used to ensure the safety of the movement of trains, and those potentially hazarded by the movement of trains. The relevant use cases for the object detection systems include driving (and use of object detection for train control) in various environments under various environmental conditions (rain, snow, fog, temperature, environmental light) in the following scenarios, e.g.:

- Departure of station / storage track, work preparation site;
- Driving on open tracks and in tunnels;
- Passing a platform (station);
- Stopping;
- Precise driving and stopping in construction sites, depots, stations, shunting yards;
- Coupling / Uncoupling;
- Autonomous parking (driving to storage track).

DB Cargo has also considered the potential use cases for OD & TID systems (DB Cargo, 2020), and identified a number of functional requirements and use cases. The requirements identified by DB Cargo relate to ***potential functions*** of OD & TID systems, including obstacle detection (such as detection of persons, railway vehicles, road vehicles, larger animals (> 1m), gates, solid objects, vegetation encroaching on the path of the rail vehicle, etc.) and environment perception (e.g., perception of track, path of train, route setting of switches, signals (including aspect) and termination of the track). A condition of these functions is that the detection should be possible from a static or moving vehicle. Therefore, according to these potential functions, obstacle detection (OD) and environment perception (EP), use cases for the OD & TID systems have been summarised, including:

- The detection and identification of objects relevant to the vehicle on which the detection system is mounted, at all speeds (OD and/or EP);
- The detection of the path of the train at all speeds so that the objects can be classified as to whether they are in the path of the train, or if they are moving towards the path of the train (EP);
- The detection of the route set for the train at low speeds, so that the route can be checked in yards (EP);
- Detection of signals and the aspect of signals, particularly in yards, to check that it is safe for the train to proceed (EP);
- The detection of rail vehicles the detecting vehicle is approaching to couple to them, and to monitor rail vehicles the detecting vehicle is moving away from after uncoupling (EP);
- To prohibit movement in the case that obstacles are detected when starting a train, for example the termination of the line or other vehicles (OD and/or EP).

The study carried out within SMART2 has identified, analysed and classified potential use cases for OD & TID systems, with respect to **two major aspects/criteria:**

- Railway operation type that the use case relates to, which determines two categories:
  - Use cases relating to general railway traffic (passengers and freight), which apply to freight operations;
  - Use cases that are specific just to freight operations;
- The grade of automation (GoA), which determines two major categories:
  - Use cases in GoA 0-1 scenarios, mostly driver-assisted;
  - Use cases in GoA 2-3-4, involving Semi-Automatic Train Operation (SATO) and Automatic Train Operation (ATO).

A general description of each of the identified use case is presented in the next sub-sections, followed, in Appendices, by UC datasheets with specific details. Use cases have been analysed with respect to the following aspects and features, which are essential for designing the OD & TID system:

- **Scope and brief description** of the use case, including the GoA conditions under which the train is operated, and scenario(s) that apply to train operations in the use case;
- **Involved stakeholders** (actors), which include the primary system actors, primary business actors and other interested parties (such as: secondary line manager, yard manager, safety investigation bodies, etc.);

- **Frequency of use,** i.e., the estimated frequency of use of the proposed OD & TID system during the operation of a freight train;
- **Pre-conditions,** which describes the conditions which must exist for the use case to be applied, both in terms of the conditions and procedures concerning the operation and control of trains, and the functionality and status of the OD & TID system;
- **Typical use case implementation** takes into consideration the main actions carried out by the OD & TID system in a number of different circumstances, the expected response to be made by the actors and systems involved in each use case, and set of circumstances with regard to the actions of the OD & TID system;
- **Post-conditions,** which describes the condition that the train ends in as a result of the action made by the OD & TID system and involved actors, in different scenarios considered for each use case;
- **Post-use scenario** describes the condition of the train and OD & TID system after the use case, with respect to specific scenarios considered for each use case;
- **Implementation constraints, risks and requirements** mainly include compatibility requirements for the OD & TID system with the ETCS and TMS systems, risks due to hazards and failures related to the system, and special requirements for each use case;
- **Estimated priority** is the priority level with respect to the requirements of users and business criteria;
- **Assumptions and open issues** describe unspecified or uncertain conditions that the OD & TID system, which might affect the implementation of the OD & TID system in particular, and the use case in general.

The datasheets also include specific conclusions for each use case. Based on the analysis and description of potential use cases, the relevance of the OD & TID system that is aimed to be developed in the SMART2 project has been assessed for each use case, with respect to its efficiency and feasibility of implementation.

The UCs defined and presented in this report will be reviewed, revised and updated with respect to the output of other S2R projects in IP2 and IP5, especially the X2RAIL-4 project. Although the output from X2RAIL-4 is still unclear in current stage, further work on this topic will be carried out within Task 1.3 of SMART2 for updating the UCs and align them with requirements in complementary projects, once the corresponding deliverables are available to public. The intention is that through collaboration and agreement with S2R members, the developed UCs will be aligned with the approach adopted in other S2R projects. The X2RAIL-4 project may also provide detailed guidance on data structure and testing approaches for the OD & TID system developed by SMART2, which may affect the decisions on communication interfaces and data exchange patterns for the development of SMART2 system.

5.2 List of Use Cases

5.2.1 General use cases applicable to freight (UC-GAF)

- Operation on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)
- Operation on mainline sections with vision issues (GoA 0-1)
- Operation on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1)
- Operation on mainline sections with specific hazards – constructions sites (GoA 0-1)
- All conventional ATO trains on mainline (GoA 2-3-4)
- All ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-3-4)

5.2.2 Freight specific use cases (UC-FS)

- Freight train with long stopping distance operating on mainline (GoA 0-1)
- Freight train with long stopping distance operating on mainline (GoA 2-3-4)
- Freight train operating on shunting yard or similar controlled environment (GoA 0-1)

5.3 General Use Cases applicable to Freight Rail

5.3.1 Operation on mainline with reduced visibility or with vision issues (limited visibility) (GoA 0-1)

In operation on mainline with Grade of Automation (GoA) 0 or 1, obstacle detection is the responsibility of the driver. However, this responsibility is shared with Infrastructure Manager staff at some specific locations, which are supervised by trackside staff (stations, monitored road crossings, sites threatened by landslides, etc.). In the existing situation, on some network sections or in certain circumstances the driver has limited visibility, which may not be sufficient to respond successfully to a possible obstacle or track intrusion in order to avoid a collision or near miss.

These situations are not clearly defined in current railway regulation and there are no common standards on driver visibility in terms of distance for detecting obstacles and/or track intrusion. In practice, the distance for detecting obstacles and/or track intrusion is considered to be the train stopping distance, which in the current freight traffic is usually between 700 and 1500 meters. However, ensuring this visibility (except for signals) is not mandatory, so it does not exist in many places. Also, with respect to signals, additional signals in advance of the stopping point might give an indication of the aspect at the stopping point, therefore, the critical issue is the visibility of the signal giving warning of the stopping point ahead, not the one at the stopping point, which might not be visible yet.

Existing railway regulation and standards define a limited number of preventive and corrective risk control measures in such situations, and many of them are prescriptive, such as reduced speed limits on lines with poor visibility of the route ahead. Currently, most of the risks associated with limited visibility are considered as broadly acceptable risks; however, these risks are still high relative to usual rail safety standards, especially given the negative impact of climate change. In addition, a significant number of rail accidents also occur under normal visibility conditions because the driver did not notice the obstacle in time for some reason (inattention, other obligations). An OD&TI system for trains operating on mainline in mode GoA 0-1 would therefore enable increased safety and efficiency of rail freight transport.

An additional role of the OD & TID system in mode GoA 0-1 may be in the event of breakdowns or degradation of traffic management system (including ERTMS/ETCS), when the OD & TID system would assist the driver to operate under Run-on-Sight (ROS) procedures. Also, in freight traffic, the OD & TID system may support enhancement of operational safety on lines with legacy modes of traffic management, e.g., non-ERTMS.

There are three specific scenarios of operations on mainline in mode GoA 0-1 with limited visibility, which are described further.

5.3.2 Operation on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)

Weather conditions, especially fog and snow, can significantly reduce visibility. In such situations, the operating regulation on most railways impose reduction of the speed but without precise limits (e.g., such as on highways), so this decision depends on the train driver's judgement. Considering that decision-making largely depends on the human factor in such situations, the possibility of a wrong decision is significant and may lead to considerable consequences (underestimation of danger endangers safety and overestimation leads to unnecessary delay and traffic congestion).

The use case for the OD & TID system is to detect objects that are hidden from view of the drivers or are unclear due to weather condition (e.g., snow or fog), and also classify the object and estimate the location of the obstacle. The data from the OD & TID system can then be used by the OD & TID system itself, or other systems (such as TMS, depending on the division of role/responsibility in different potential system architectures), to estimate the position of objects relative to trains, and potentially provide an enhanced image and distance information to the driver. In addition, the data can be used by a decision-making process in the OD & TID system, the ATP/Train control system, or the TMS to make decisions about train control responses, such as stopping the train, slowing the train, or sounding an audible warning. The driver, ATP, and/or TMS would then implement the appropriate train control action (e.g., stop train, slow train, or sound audible warning) significantly reducing the risks associated with bad weather conditions and increase the efficiency of freight rail transport. A potential additional role of the obstacle detection system is the detection of signals at least in GoA 0.

The parties involved in train operations on mainline are ***the train operator*** (RU) and ***the traffic management*** (IM). In cases of maintenance train, the infrastructure management and the train operator might be the same organisation.

Signalling and ATP system and procedures are not standardised across the EU; in GoA 0-1, the OD & TID system is a decision support system for the driver, therefore, it has to be compatible with the HMI. In GoA 1 it has an additional role in informing the activation of ATP, which requires compatible interfaces between OD & TID and ATP. Considering that collisions involving trains and near misses on mainline are required to be investigated under the EU railway safety regulation, an additional role and/or requirement is expected in the OD & TID system. i.e., to allow the reliable recording and storage of all information relevant to incidents with obstacles and track intrusion.

5.3.2.1 Operation on mainline sections with poor vision conditions (GoA 0-1)

The scenario of this use case considers sections and/or conditions that are characterised by circumstances that reduce the driver vision, such as low light levels, high contrast, rapidly changing light levels, glare, etc. These circumstances typically occur at specific times of the day (e.g., night-time, sunrise, sunset) and/or in specific locations (e.g., tunnels, stations, etc.).

According to TSI OPE, visibility in night-time und other low light conditions is improved by use of locomotive front lights:

*TSI OPE (EU) 2019/773, point 4.2.2.*1.2:

> *"The front-end lights shall optimise train detectability (marker lights), provide sufficient visibility for the train driver (head lights) by night and during low light conditions and shall not dazzle the drivers of oncoming trains"*

However, in practice, the visibility in night conditions or in long unlighted tunnels is well below the braking distance even with the use of high-intensity headlights. In addition, it is often not possible to use the high-intensity headlights on multi-track lines, stations, lines parallel to roads, etc., so in these conditions the driver is generally unable to notice potential obstacles at a satisfactory distance. A similar problem with limited visibility may result from low angle sunlight (either creating glare in the drivers vision or large areas of high contrast between well-lit and shaded areas, making it difficult to see both at the same time) or rapid changes in light level (making it difficult for the drivers vision to adjust rapidly and maintain the same level of vision).

Regardless of the significant risk, in most countries railway regulations traditionally do not define any special risk reduction measures for night driving (reduction of speed etc.).

Therefore, a potential use case for a OD & TID system is to detect and classify objects, including those not visible or unclear to the drivers due to vision issues (such as low or changing light levels), the minimum additional information from the OD & TID system being an estimate of the location of the detected object (in this instance the terms “object” or “obstacle” refer to all types, including persons). The data from the OD & TID system can then be used by the OD & TID system itself, or by other systems (such as TMS, depending on the division of role/responsibility in different potential system architectures), to estimate the position of objects relative to trains, and potentially provide an enhanced image and distance information to the driver. In addition, the data can be used by a decision-making process in the OD & TID system, the ATP/Train control system, or the TMS to make decisions about train control responses, such as stopping the train, slowing the train, or sounding an audible warning. This would significantly reduce the risks of operating at night and in low light conditions due to a driver not observing a hazard and reacting in time.

In this use case, the OD & TID system could be also designed with the additional environment perception functionality of detecting the signals and their aspect, which would be relevant in GoA 0.

The parties involved in train operations on mainline are ***the train operator*** (RU) and ***the traffic management*** (IM). In cases of maintenance train, the infrastructure management and the train operator might be the same organisation.

5.3.2.2 Operation on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1)

Due to the track geometry, terrain geography, buildings and structures near the track and infrastructure, in certain places it is not possible to provide satisfactory sight lines for a driver (or detection device on the front of a train) to see a significant distance (such as the breaking distance of the train) ahead, i.e. the view from the front of the train is obstructed. The most common reason for this is sharp curves, but even on other parts of the track, objects or vegetation can obscure the view on the belt next to the track from which a potential obstacle may appear, or of the track a significant distance ahead. Although in sharp curves the speed of trains is limited and, hence, the stopping distance is shorter, the stopping distance can still be longer than the available visibility. Regardless of the significant risk in such places, in most countries traditional railway regulations do not provide any specific measures to control these risks, except in some specific cases, such as areas of increased risk from floods and landslides, and TID on bridges of high-speed lines. In addition to the reduction of speed, in areas where there is an increased risk of landslides; in recent times, drones have also been used to monitor the condition of the track and the surroundings at intervals and after inclement weather. However, also in these exceptional cases, the coverage of OD & TID is not currently complete with regard to providing detection of all potential obstacles in the path of every train where the visibility and drivers vision is not sufficient for the driver to see at least the minimum stopping distance ahead of the train; therefore, the control of the risks from the potential hazards at these locations largely depends on the driver's judgment, and the general acceptance of a certain level of risk in the operating procedures/practices.

Therefore, a potential use case for an OD & TID system is to detect objects that are hidden from view of the front of the train by items and structures that are not obstacles to the train but block line of sight to it and estimate the location of those objects. The data from the OD & TID system can then be used by the OD & TID system itself, or other systems (such as TMS, depending on the division of role/responsibility in different potential system architectures), to estimate the position of objects relative to trains, and potentially provide an enhanced image and distance information to the driver. In addition, the data can be used by a decision-making process in the OD & TID system, the ATP/Train control system, or the TMS to make decisions about train control responses, such as stopping the train, slowing the train, or sounding an audible warning. This system would significantly reduce the risks on sections with reduced visibility due to permanent causes.

The parties involved in train operations on mainline are ***the train operator*** (RU) and ***the traffic management*** (IM). In cases of maintenance train, the infrastructure management and the train operator might be the same organisation.

Unlike the previous cases where the primary obstacle detection system is on the board of the train, the use of trackside devices to provide the required level of OD & TID coverage is likely to be essential in this case, although trackside devices can also be of use in the other cases to provide OD & TID coverage in those conditions as well. Therefore, it is essential that any trackside equipment that may be part of an OD&TID system is compatible with the signalling and ATP systems of the network on which they are used. Considering that collisions involving trains and near misses on mainline are required to be investigated under the EU railway safety regulation, it is expected that that an additional role and/or requirement might be that the OD & TID system should allow the reliable recording and storage of all information relevant to incidents with obstacles and track intrusion.

5.3.3 Operation on mainline sections with specific hazards - constructions sites (GoA 0-1)

This section identifies and explains the potential use of an OD & TID system near construction/maintenance sites for a freight train operating with Grade of Automation (GoA) 0 or 1 (driver controlled). The detection of possible hazards near construction/maintenance sites can be useful for safe and efficient freight train operation. Several ***specific scenarios***, based on the location of the construction/maintenance site, may be considered:

- The main potential use for OD & TID with regard to maintenance/construction sites is to safeguard the passage of trains on adjacent tracks open to normal traffic and staff working in the area by detecting if any personnel, equipment or material associated with the maintenance/construction site (track possession) is obstructing the lines open to traffic. The use of the OD & TID system in the case of engineering possession on adjacent track, including construction/maintenance sites, and/or trackside worksites is detection and classification of the objects on adjacent track, or which impinge on (or present a hazard to) the track(s) open to normal traffic, when construction/maintenance is ongoing or has been completed. The actors in these situations (locomotive operator, signaller, rail area operations manager, rail infrastructure manager, railway operator) can be informed and appropriate actions can be taken. For example, the driver of a train in normal traffic on a track adjacent to the possession can be warned of an obstacle ahead (e.g., a member of staff stepping, or excavator arm swinging beyond the possession) and slow the train, stop the train, or sound the audible warning. Another example would be that the person responsible for the possession can be informed that an obstacle left in the possession has been detected so that it can be removed before the possession is lifted.

- Another scenario for the use of the OD & TID system is on a straight section of line (or section with sufficient line of sight ahead of the train) within or approaching a construction/maintenance site. In this location-based scenario, the OD & TID system would be able to detect the potential objects and hazards when construction/maintenance work is carried out on the track. An additional role for the system could be to detect markers for the start and end of the possession and possibly identify it as a specific special type of obstacle. The detection could be done by onboard equipment, which would inform the driver and locomotive operator based on the identified hazards when approaching construction sites. The system might also have an additional role when track possession due to construction/maintenance ends on the previously occupied and adjacent track sections. For example, if an obstacle (e.g., material or equipment left over from the construction/maintenance process by mistake) is detected on the route after track possession ends, the necessary action can be implemented. Furthermore, if an object or intrusion is detected and there is an alternative route on which operation can be maintained, traffic management system can be updated for necessary actions to continue train operation.
- In another scenario, the OD & TID system may be used when elements pertaining to construction/maintenance site are blocking trains' view. In this location-based scenario, the OD & TID system could detect the potential objects and hazards when construction/maintenance work blocks the line of sight between the front of the train and the site, obstacles adjacent to the site, or obstacles beyond the site. Examples of this scenario include construction/maintenance work on tunnels, tight curves blocked by obstruction, track sections where the visibility is reduced due to vegetation. The use of the OD & TID system in this scenario would require a more complex design of the system, which could include, e.g., a trackside or an airborne subsystem, and communication and coordination between all elements.
- The OD & TID system may be, also, used when construction/maintenance site is located in the vicinity of level crossings. In this location-based scenario, the OD & TID system would detect the potential objects and hazards when construction/maintenance work is carried out in the vicinity or at level crossings. The use of the OD & TID system in this scenario would require a trackside subsystem, along with communication and coordination features.

Requirements are the same as the two previous location-based scenarios. In addition to detecting potential obstacles on the track and/or track intrusion, the OD & TID could also identify potential hazards due to road vehicles and pedestrians.

In general, the use case initiates with the OD & TID system (onboard, airborne and trackside) scanning for, and detecting obstacles and/or intrusions and estimating their location. There are a number of potential system architectures for determining the relationship between the detected objects and trains in the local area depending on the division of responsibilities and decision making processes between the interested parties and systems involved (detection, train control (including driver), train protection, traffic management). For instance, the OD & TID system could directly determine the distance from the front of the train and display the information to the driver (or send information to ATP), or all detections could be relayed to the traffic management system, which uses the location of the obstacle and train to determine the distance to the train (and relevance to it) and sends that information to the driver (and/or ATP). One significant factor in relation to OD & TID is the determination of the path of the train; this could be: i) determined and used by other systems for making hazard assessments and decisions; ii) determined by the OD & TID system, or iii) be an external input to the OD & TID system from, for example, the TMS.

Potential ***hazardous obstacles*** for this specific use case are

- construction/maintenance site personnel,
- construction/maintenance site tools and instruments,
- any vehicle used for construction/maintenance purposes.
- any obstacle not related to the construction/maintenance site, but which the view of from the front of the train might be blocked by the construction/maintenance site.

The main role of the OD & TID system in this use case is to detect and classify the above-mentioned objects near construction/maintenance sites. Through a human machine interface, the locomotive operator can be informed about detected hazards based on detection and classification of objects and distance. Therefore, the driver and/or ATP system can implement required actions. Potential ***additional scenarios*** and subsequent additional role of the OD & TID system for this use case include:

- *Planned construction/maintenance activities.* This scenario involves planned processes and activities of construction/maintenance for possession of a track section. In addition to detection of potential obstacles (objects pertaining to the planned activities), the OD & TID system might be able to detect and classify objects that can appear beyond the planned construction/maintenance activities and identify these as potential hazards. It could provide information to other key actors and, based on the hazard, necessary information can be passed to driver and/or ATP.
- *Emergency engineering construction/maintenance.* In this scenario, the locomotive operator might not be informed in advance. Even though the function of the OD & TID system is the

same as it is for planned activities scenario, the role of the system is critical in this case. Based on the classification of the object and/or intrusion, necessary actions can be taken by locomotive driver and other actors (signaller, rail area operations manager, rail infrastructure manager, railway operator) can be informed about these actions. Based on the evaluated risks and hazards, necessary information can be transferred to train control/traffic management system.

- *After ending track possession due to construction/maintenance.* Additional role of the OD & TID system would be to check the construction/maintenance site after track possession ends and detect unexpected construction/maintenance site objects. In this scenario, these objects are likely to be equipment and materials left behind on site. Potential hazards and risks are identified, the drivers of approaching trains warned of the hazards, and necessary information can be transferred to train control/traffic management system.

The use of the OD & TID system in location- and plan-based scenarios is as follows. When the construction/maintenance site is on a straight section of track (or section with sufficient line of sight ahead of the train) and the OD & TID system detects an intrusion, potential hazards and risks are identified and this information is passed to locomotive operator, ATP (if activated by OD & TID system directly) and train control/traffic management system. Necessary actions can be taken based on the risks, including stopping, braking or slowing down the vehicle to a specified speed for safe passage past/through construction/maintenance site, and, if available, based on the signalling and the availability of tracks, diverting the route of vehicle. In all location-based scenarios, actions that can be taken are the same for this use case. The OD & TID system could be especially useful to provide information to train control/traffic management system when there is an alternative route that the vehicle can be diverted onto to avoid the hazard, and the traffic management system can reorganise the traffic afterwards. The importance of the identification of risks and hazards by the OD & TID system is important for scenarios involving planned engineering works; however, this is especially important in scenarios involving emergency engineering construction/maintenance. Stakeholders such as infrastructure manager, signaller, rail area operations manager, railway operator and construction/maintenance company would be interested in the detection and classification of the objects and intrusion. Therefore, the results of the detection can be shared with these parties in a coordinated way.

Pre-conditions for the OD & TID system to be used in this use case are a continuous communication between OD & TID system, vehicle and the key actors (locomotive operator, signaller, rail area operations manager, rail infrastructure manager, railway operator).

Post-condition is the successful implementation of the actions by involving parties in case of a construction/maintenance site object and/or intrusion is detected.

5.3.4 All ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-4)

In this use case (for GoA 2-4), the use of the OD & TID system (on driving unit/locomotive and/or trackside) might be required to detect obstacles and potential hazards close to the path of the train, and classify those hazards, the classification being used by the train control or yard management system to determine the safe extent of movement. The detection role has some similarities to that on the mainline, however, the assessment criteria for detection may be different in the yard environment. Potential additional roles (based on additional environment perception functionalities) for the OD & TID system in the yard environment include:

- detecting and range finding with respect to other rail vehicles in the path of the train; this could either be an active part of the train control, or a safety supervision role to prevent collisions or conflicting movements;
- detecting the route setting in the path of the train; that is detecting the position of switches so that the train control and/or yard management system can determine/confirm the route set for the train and that the switches are fully set against a stock rail and therefore safe for the train to pass;
- detecting location reference points (for example loading point markers or fouling point markers) so that the train control and/or yard management system can position the train or vehicles accurately.

The role of track intrusion systems in the yard environment could be more focused on tracking potential obstacles within the railway boundary rather than just detecting obstacles which have crossed the railway boundary, as, typically, in the yard environment staff and equipment are expected to be close to the track. The train control and/or yard management system could then use that tracking information to evaluate risk, assess hazards and implement actions such as warning staff or equipment operators in the path of the train or stopping the train. The OD & TID systems could have an additional role in ascertaining if a train is safe to move after it has been stopped, for example identifying if there are staff or equipment conducting operations anywhere along the length of the train, which could be jeopardised if the train were to move; this role would be complementary to other safety interlocks associated with staff or equipment performing operations on the train. In parallel with the increasing automation of train operation, there might be more automation of yard operations such as coupling and loading/unloading, and the systems could be linked to reduce the need for human intervention and detection; however, there would likely be at least a transition period when ATO would be required to operate in conjunction with current practices with only slight alteration to procedures.

There needs to be coordination between the parties involved in train operations in yard areas; these would primarily be the ***locomotive operator*** (including all types of motive power) and ***the operator of the yard***, including marshalling yards and yards for servicing, maintenance and storage. In some cases, the yard operator and the locomotive operator might be the same organisation. The mainline infrastructure manager would also have an interest in the procedures for interchange of traffic between the mainline and yards.

Another interested parties would be the freight customers (who might also operate their own yards and locomotives) and, additionally, might have responsibility for loading/unloading equipment. The third category of interested parties would be the passengers, although their interest would be limited to the trains arriving in service from the yards as scheduled. There would be a requirement for procedures for requesting moves, prioritising and authorising moves (a yard management/yard TMS), setting routes for moves, performing the handover between yard and mainline, and a safety override for all interested parties to prohibit movement of specific trains or on specific sections of track as required. The responsibilities assigned in the process/system would influence the technical interface between the detection systems and other systems, although subsystems might still provide safety supervision in addition to the system in overall control.

5.3.5 All conventional ATO trains on mainline (GoA 2-4)

In this use case, *"conventional"* refers to trains of typical lengths, weights and running at typical operating speeds, as opposed to those with longer stopping distance, which have been considered a specific use case. In Europe, the typical freight trains in this category are about 500 m long, weighing up to 2000 t and operating with maximum speeds between 80 and 120 km/h. Most of these trains operate in only-driver modes (GoA 0-1). Regardless of the method of train control the driver has other important obligations besides driving (control of the technical condition of the locomotive and wagons, brake testing, taking corrective actions in case of failures, cargo monitoring, supporting documentation, etc.), the possibility of automation, i.e., implementation of GoA 2-4, depends on the possibilities to automate the operations or for track-side staff to take them over. Also, trains carrying dangerous or sensitive cargo (e.g., fuel, chemicals, military transport) will still need to be attended for safety and security reasons, since, in the event of any incidents (e.g., fire, leakage of dangerous gases, theft, etc.) on such trains, a rapid intervention is essential and waiting for the arrival and intervention of staff from other locations is unacceptable. Some categories of ATO trains must have driver on board (GoA 2) and some can be attended with lower level staff (GoA 3), which can carry out these safety critical roles; however in the case of no staff being required for supervision of train control or degraded working, the issue of fulfilling these safety critical roles would remain to be resolved.

For a conventional freight train operating on mainline with GoA 2–4, the OD & TID system (on driving unit/locomotive and trackside) must detect, classify and estimate the location of objects intruding on the track or within the railway property boundary (areas accessible to the public or staff which are not expected to intrude onto the railway might be excluded or monitored), i.e., in general terms, the obstacle. Depending on the system architecture and division of responsibilities between the interested parties, the estimation of the distance of the obstacle from the any one train can be determined in a number of ways and requires knowledge of the trains' path. For instance, the OD & TID system could directly determine the distance of the obstacle from the front of the train and send the information to the train control system and/or TMS, possibly displaying the information to the driver (GoA 2)/ attendant (GoA 3). One possible alternative is that all detections of the OD & TID system could be relayed to the Traffic Management System (TMS), which uses the location of the obstacle and train to determine the distance between them (and relevance to it); the TMS sends that information to the train control system (and possibly driver/attendant) or modifies the movement authority and/or target motion profile of the train. Similarly, the decision-making process (the train control actions to implement based on the obstacle detection and classification) could be the responsibility of the train control system, the TMS, or a combination of both (i.e., TMS with overall responsibility but with the train control system being able to respond in an emergency).

For conventional freight trains under normal conditions, there is no difference between the requirements for OD & TID systems for GoA 2-3 and GoA 4 modes. Differences in requirements for this system may be related to operation in case of disruption and operation after stopping a train due to an obstacle, GoA 4 mode means that the train is automatically controlled in the event of a disruption. Moving in case of disruptions on the line may require a change of tracks, i.e., a reversing move, etc., which could be an additional role for the OD & TID system (i.e., to supervise the safe movement of the train when the leading vehicle is not equipped with its own OD & TID equipment). Another difference in requirements is related to the mitigation measures to deal with the obstacle after stopping a train due to an obstacle. Many categories of obstacle (e.g., small animals, thin layers of soil, smaller trees, minor flooding) do not jeopardise the train safety or require extensive administrative procedures and activities by government bodies and could be dealt with or assessed by a member of staff from the train. In these situations, the most important thing is to resume traffic as soon as possible; however, if there is no member of staff on the train to implement a response, serious disruption to rail traffic could occur until a member of staff from another location arrives to deal with minor obstacles. That is, minor obstacles may have similar impact with more significant obstacles, which require more resources to implement the response. In GoA 2-3, these activities can be performed by the driver (GoA 2)/ attendant (GoA 3) in communication with Traffic management. However, in GoA 4 the OD & TID system may be able to provide more detailed information about the obstacle so that the automated TMS or remote operator could make a decision on whether it's safe to continue the traffic or not, without sending staff to the location.

The parties involved in this use case are the ***train operator*** (RU) and ***the traffic management*** (IM). In cases of maintenance train, the infrastructure management and the train operator might be different departments of the same organisation. The IM on secondary line (without ERTMS) and yard operator (marshalling yards and yards for servicing, maintenance and storage) would also have an interest in the procedures for interchange of traffic between the mainline and secondary lines and yards.

Considering that automation at GoA 2-4 on the mainline is only likely to be implemented in the EU as part of ERTMS, all operating procedures and interfaces must comply with the specifications of this system. Different rules may be required and applied only in the case of degraded mode operation or emergency situations, i.e., national or local IM rules may be in force. However, these rules are currently not fully applicable in case of GoA 4 (total automation train control). Considering that collisions involving trains and near misses on mainline are required to be investigated under the EU railway safety regulation, it is expected that that an additional role and/or requirement might be that the OD & TID system should allow the reliable recording and storage of all information relevant to incidents with obstacles and track intrusion.

5.4 Specific Freight Use Cases

5.4.1 Freight trains with long stopping distance operating on mainline

Different types of trains require different distances to stop, the stopping distance depending on the momentum of the train (mass and speed), effectiveness of the braking system (how much kinetic energy it can dissipate) and the brake control system (whether each brake is controlled individually so that the optimum effectiveness can be achieved, or all of the brakes are limited by the least effective one, as well as if the operation of the brakes is monitored, e.g., by wheel slides sensors, etc.). In addition to the theoretical performance of the braking system, there are other factors that also affect the stopping distance, such as the level of adhesion between the wheel and the rail and the stability of the train formation in response to the forces generated between vehicles under braking. In passenger units, the connection between vehicles is generally quite rigid, the braking performance of the vehicles is similar, the brake control systems are more sophisticated and the formations are not very long, therefore, the forces between vehicles are generally lower and the stability of the train is better than for freight trains.

This specific use case relates to freight trains with a stopping distance significantly greater than that of conventional freight and passenger trains; this applies to freight trains that:

- Are exceptionally long; and/or
- Are exceptionally heavy; and/or
- Travel at higher speeds than conventional freight trains; and/or
- Carry potentially hazardous or volatile freight (which needs more careful train handling, i.e., a smoother braking regime).

In the cases where the stopping distance of freight trains is longer, the OD & TID system needs to detect hazards further in advance of the path of the train in order for the train control and/or traffic management systems to make train control and/or movement authority decisions in a timely manner to enable the train to be stopped or slowed before encountering the hazard. There are several implications of the increase in distance that OD & TIDs need to detect hazards in advance of trains on the OD & TID system; the most significant of these are:

- Increasing distance ahead of a train that detection is required means that there is a higher probability not to detect an obstacle at the same distance or greater from the front of the train than the stopping distance due to either technical limitations, environmental effects, or the view being blocked by the topology of the route or its surroundings. Therefore, it is less likely that only detection from the front of the train would be adequate for safe operation, increasing the need for trackside detections systems and integration of data from multiple trackside detection systems, to achieve sufficient hazard detection coverage in ahead of trains with long stopping distances.
- If there is an increasing need for trackside detection systems and integration of data from multiple trackside detection systems to achieve sufficient hazard detection coverage in ahead of trains with long stopping distances, then:
  - There will also be an increase in the number of active communication interfaces and the communication bandwidth utilised by the detection of hazards in front of any one train with a long stopping distance. In this instance, an “active” OD & TID element (an element the data from which is directly relevant to a train in traffic) should be considered within the minimum number of elements required to detect hazards within the stopping distance ahead of a train, even though they might be detecting hazards, interfacing and communicating at other times. However, the OD & TID system might be specified with sufficient communication interfaces and simultaneous bandwidth to cope with the hazard detection results from all elements of the detection system at any one time.
  - There will also be an increase in the priority for minimising the time for communication, processing and decision making (considering that the input from more elements of the OD & TID system would have to be taken into account and the greater distance in advance of a train those elements would be) in order for the appropriate decisions to be taken, communicated and implemented by the HMI, driver, ATP, ATO, and/or TMS.

In addition to the primary role of the OD & TID system, there is also a potential additional role for the system in the case of trains with long stopping distances. Since these trains are most likely extremely long it would be difficult for the condition of the train to be monitored or investigated from the locomotive, there is potential that some of the trackside detection systems (or the detection systems on passing trains) could be adapted to recognise or investigate anomalous situation on the train. Such anomalous situations might include risks for derailment of the train, leaking or out of gauge cargo, hot axle boxes, locked brakes, or fire. This role would also be applicable to other use cases, but it is of the most potential value with longer trains.

In general, the OD & TID system use case for freight trains with long stopping distances has many similarities to the use case for high speed trains, which also have longer stopping distances than conventional trains. However, there are significant differences, for example for a freight train and high speed train with the same long stopping distance, there would be a higher priority in reducing the time taken for processing, communication, decision making and implementing responses for high speed trains since the high speed train will have travelled further in that time (i.e., the reaction distance is longer). Other differences include the breaking performance, sophistication of the brake control system, and stability of the train under braking of high-speed trains, which might mean that in cases where the normal service braking distances might be similar, the emergency braking distances of high-speed trains might be shorter.

Considering the grade of automation (GoA), there are 2 potential specific use cases for OD & TID systems in situations when freight trains with longer stopping distance are running on the mainline, which are described further.

5.4.1.1 *Freight trains with long stopping distance operating on mainline in GoA 0-1 scenario*

Unlike other use cases where stopping distances are shorter, there is likely to be few occasions or little chance that detection from the front of the train only would be sufficient. Therefore, in this use case the OD & TID would almost certainly have to include interfaces to the HMI and/or ATP from trackside elements of the system (and more of them) and integrate those inputs into the HMI display or ATP decision, respectively, as well as those on the front of the train. The information from the OD & TID system could also be sent to the TMS (which would need more active inputs for each train to cover the reaction and stopping distance ahead of a particular train), which could modify the movement authority or target motion profile provided to the driver (with or without additional information on the hazard displayed on an HMI) to implement the appropriate train control response. Also, the information the HMI displays to the driver (e.g., enhanced image of any particular hazard, distance to detected hazard, hazard classification and risk assessment, etc.) might need to be more sophisticated than in other cases to better inform the judgement of the driver, since the consequences of the driver's decision in the case of a train with a long stopping distance may be more severe. This is because in the case of freight trains with a long stopping distance, due to the common characteristics of these trains, the chances of a derailment or coupling failure in the event of an emergency brake application or miss-management of the inter-vehicle forces are greater. Also, the time for recovery from a braking response to a detected hazard (longer brake release time, slower acceleration) is likely to be longer, which has implications for service disruption, therefore, it is more critical that the driver or ATP makes the correct decision.

The other significance of the likely need of involvement of trackside detection systems is that it would mean that the infrastructure manager (assuming they are the operator of the trackside systems) would definitely be another interested party in terms of the OD & TID system.

5.4.1.2 *Freight trains with long stopping distance operating on mainline in GoA 2-3-4 scenario*

Similar to the case of GoA 0-1 operation, for GoA 2-4 the main distinguishing feature of the OD & TID system, for the case of freight trains with a long stopping distance, will be that for each train a higher number of detection elements would need to be utilised at any one time, and the greater distance in advance of a train that some of those elements would be. This means that at any one moment the OD & TID system would need to interface and communicate with more elements in relation to any particular train. The interfacing and communication with the elements of the system could be controlled and managed with respect to the location of the train (train location information supplied to the OD & TID system through an interface with the TMS) and the hazard detection information communicate to the ATO system on the train (with information displayed to the supervising driver on a HMI in the case of GoA 2). Alternatively, or in addition, the OD & TID system would interface and communicate with the TMS, and the TMS would modify the movement authority or target motion profile of the ATO accordingly (with information displayed to the supervising driver on an HMI in the case of GoA 2).

5.4.2 Freight train operating on shunting yard or similar controlled environment (GoA 0-1)

For a freight train operating in a yard with Grade of Automation (GoA) 0 or 1, the OD & TID system (on driving unit/locomotive and/or trackside) might be required to detect obstacles and potential hazards close to the path of the train, and classify those hazards, the information being used by the driver, through the HMI interface, locomotive ATP, or yard management system to determine the safe extent of movement. Conventionally, an ATP system is only active/used on a locomotive in areas controlled by signals/TMS/ERTMS/ETCS; however, one of the potential system architectures would be for the ATP to be used as an interface by the OD & TID system of yard management system to stop a train if a critically hazardous situation is detected – the decision-making being carried out by one of the systems based on the information from the OD & TID system. The detection role has some similarities to that on the mainline, however, the assessment criteria for detection may be different in the yard environment. Potential additional roles (based on additional environment perception functionalities) for the OD & TID system in the yard environment include:

- detecting and range finding with respect to other rail vehicles in the path of the train; this could either be an active part of the train control, or a safety supervision role to prevent collisions or conflicting movements;
- detecting the route setting in the path of the train; that is detecting the position of switches so that the train control and/or yard management system can determine/confirm the route set for the train and that the switches are fully set against a stock rail and therefore safe for the train to pass;
- detecting location reference points (for example loading point markers or fouling point markers) so that the train control and/or yard management system can position the train or vehicles accurately.

The role of track intrusion detection systems in the yard environment could be more focused on tracking potential obstacles within the railway boundary rather than just detecting obstacles which have crossed the railway boundary, as, typically, in the yard environment staff and equipment are expected to be close to the track. The driver, ATP, and/or yard management system could then use that tracking information to evaluate risk, assess hazards and implement actions such as warning staff or equipment operators in the path of the train or stopping the train. The OD & TID systems could have an additional role in ascertaining if a train is safe to move after it has been stopped, for example identifying if there are staff or equipment conducting operations anywhere along the length of the train, which could be jeopardised if the train were to move; this role would be complementary to other safety interlocks associated with staff or equipment performing operations on the train. In parallel with the increasing automation of train operation, there might be more automation of yard operations such as coupling and loading/unloading, and the systems could be linked reducing the need for human intervention and detection; however, there would likely be at least a transition period when ATO would be required to operate in conjunction with current practices with only slight alteration to procedures.

There needs to be coordination between the parties involved in train operations in yard areas; these would primarily be the ***locomotive operator*** (including all types of motive power) and ***the operator of the yard***, including marshalling yards and yards for servicing, maintenance and storage. In some cases, the yard operator and the locomotive operator might be the same organisation. The mainline infrastructure manager would also have an interest in the procedures for interchange of traffic between the mainline and yards.

In the case of yards, there might not be a standard operating system and procedures, however, a locomotive could visit yards with different systems, so it would need to be compatible with all yards, or a yard might have duplicate systems to ensure compatibility with all locomotives. Therefore, at least either the OD system on the locomotive needs to be compatible with (one of) the yard operating system(s) using the OD data from the locomotive, or the yard OD & TID system operates independently of the locomotive OD system and only needs to be compatible with the locomotive control system. The secondary interested parties are the freight customers (who might also operate their own yards and locomotives) and, additionally, might have responsibility for loading/unloading equipment. There would be a requirement for procedures for requesting moves, prioritising and authorising moves (a yard management/yard TMS), setting routes for moves, performing the handover between yard and mainline, and a safety override for all interested parties to prohibit movement of specific trains or on specific sections of track as required. The responsibilities assigned in the process/system would influence the technical interface between the detection systems and other systems, although subsystems might still provide safety supervision in addition to the system in overall control.

6 Conclusions

This report overviews the current technologies available for Obstacle Detection and Track Intrusion Detection in the railway environment, and the current use of those systems in the context of driver assistance, ATO, and current Traffic Management systems. It also provides some background on ATO systems and TMS in Europe, with a focus on the aspects where OD & TID systems could be relevant to the operation of trains.

The focus of the study presented in this report was to identify and analyse the future potential use cases for a novel OD & TID system in the context of the safe and reliable operation of freight trains, and trains in general. The scope of such a system, in terms of object detection, would be to detect any object and, therefore, potential obstacles on, near, or approaching the railway track, which would be in the path of approaching trains. The intention of such a system, in terms of intrusion detection, would be to detect the intrusion of objects, persons and vehicles into the trackside environment, which could be, or become a hazard to approaching trains and could themselves be at risk from the approaching trains. The objective of detecting these obstacles and intrusions is to capture and enable that information to be provided to, and used by railway operators and operating systems, such as drivers, automated train control systems, and TMS, to implement the appropriate response to the perceived hazard presented by the object, either to passing trains or the detected object itself.

The potential use cases for an OD & TID system identified have been divided into two main categories, which are:

- General Use Cases Applicable to Freight (UC-GAF) - use cases which apply to the operation of all types of rail traffic, including freight;
- Freight Specific Use Cases (UC-FS) - use cases with specific relevance to the operation of freight trains.

The use cases have been further categorised by the GoA involved in the operation of the trains and specific characteristics of the use case, such as specific types of hazard or sets of conditions. Details of all use cases that have been identified are included in specific UC forms, in the appendices.

The relevance of SMART2 concept to the identified use cases has been assessed and is presented in sub-section 6.4 and within specific conclusions for each use case, in appendices. The highly relevant use cases will be taken into consideration in the development and testing of the proposed OD & TID system within the SMART2 project.

The following sub-sections summarise the main conclusions for the identified use cases, with respect to essential aspects concerning technology developments foreseen in the SMART2 project and potential further exploitation of OD & TID systems, in general. Based on these specific conclusions, the SMART2 project will better define its focus and prioritise further technical activities.

6.1 Overall priority/importance of implementing the different use cases

The output of OD & TID system is considered as being expected to be compulsory for some on-board or trackside systems responsible for the operation of trains, and is considered as being expected to be advisable, or a beneficial safety enhancement for others, depending on the use case. In each use case the role of the proposed OD & TID system had been classified into different levels due to its frequency of usage with respect to the operation of trains. The priority/importance of implementing the OD & TID system in each use case is summarised below.

Table 2: Estimated overall priority/importance of implementing the different use cases

Level of priority/ importance	Use case	Justification
Very high	**GAF-05** - OD & TID use for all conventional ATO trains on mainline (GoA 2-4) **FS-02** - OD & TID use for/in freight train with long stopping distance operating on mainline (GoA 2-4)	Some form of OD & TID would almost certainly be required as input to automated train control to make risks of ATO acceptable for national/international networks (particularly, the increased risks associated with trains with long stopping distances); therefore, OD & TID would be in continuous use.
High	**GAF-06** - OD & TID use for all ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-4)	Some form of OD & TID would almost certainly be required as input to automated train control in yards to make risks of ATO acceptable, and ATO in yards is likely to be an extension of ATO on mainlines; therefore OD & TID in yards would be required daily at most starting, calling and end points.
Medium-high	**FS-01** - OD & TID use for freight trains with long stopping distance operating on mainline (GoA 0-1)	Medium-high impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could significantly improve safety) and medium-high probability of scenario occurrence.
Medium	**GAF-01** - OD & TID use for freight train operating on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)	Low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and high probability of scenario occurrence.

	GAF-02 - OD & TID use for freight train operating on mainline sections with poor vision conditions (GoA 0-1) **GAF-03** - OD & TID use for freight train operating on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1)	
Medium-low	**GAF-04** - OD & TID use for freight train operating on mainline sections with specific hazards - constructions sites (GoA 0-1)	Low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and moderately high probability of scenario occurrence. Priority for trains passing work sites is probably higher than trains entering work sites, since trains in work sites run at reduced speed (ROS), however the risk of obstacles is greater within work sites.
Low	**FS-03** - OD & TID use for freight train operating on shunting yard or similar controlled environment (GoA 0-1)	Low impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, and implementation could slightly improve safety), even though there is a high probability of scenario occurrence. If being implemented, OD & TID in yards would be used daily at most starting, calling and end points.

6.2 Estimation of complexity of OD & TID system for the different use cases

The use cases for OD & TID system are primarily identified with respect to different GoA levels and further identified with respect to specific train operation scenarios. Some of the use cases are related to operation of all conventional trains using ATO on the mainline, including freight trains, and some of the use cases are specified based on special characteristics of operating freight trains. The OD & TID system should have sufficient interfaces with the other systems involved in operating the trains in that use case, such as ETCS and TMS systems, and ATP and ATO systems, and would require integration with those systems. The complexity of the OD & TID system, and the complexity of integrating it with the other systems and procedures involved in operating the trains varies between use cases. The development of the OD & TID system also needs to consider the difficulties of applying appropriate sensors and their supporting software. Therefore, the complexity of potential OD & TID system concepts that may be developed for each use case has been estimated and is summarised below.

Table 3: Estimated complexity of OD & TID system for the different use cases

Complexity of OD & TID system	Use case	Justification
High-medium	**GAF-05** - OD & TID use for all conventional ATO trains on mainline (GoA 2-4) **GAF-06** - OD & TID use for all ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-4) **FS-02** - OD & TID use for/in Freight train with long stopping distance operating on mainline (GoA 2-4)	The design and complexity of implementation of the OD & TID system depends on the overall ATO system architecture and division of responsibilities for decision making (in OD & TID, ATC, TMS, Yard Management System, etc.). In any case, the system is likely to be an onboard and trackside sensor system using different types of camera and supporting technologies (trackside only might be sufficient), with interface to other ATO systems and interface to driver/attendant HMI (either direct or from another system, e.g., TMS). The complexity of systems associated with operations in yards may be increased due to the need to ensure compatibility (as standardisation may be less/different than on mainline), and/or due to complex hazards in yards (e.g., staff and loading equipment close to trains).
Medium-high	**GAF-03** - OD & TID use for freight train operating on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1) **FS-01** - OD & TID use for freight trains with long stopping distance operating on mainline (GoA 0-1)	Most likely a fusion/combination of inputs from on onboard sensor system and trackside elements using different types of camera and supporting technologies. Interface is via driver with some relatively simple interface to ATP; interface with TMS would be more complex.
Medium	**GAF-01** - OD & TID use for freight train operating on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)	Most likely an onboard sensor system using different types of camera and supporting technologies, and interface is via driver with some relatively simple interface to ATP. The complexity may increase if additional trackside elements would be required, and/or if interfacing with TMS.

	GAF-02 - OD & TID use for freight train operating on mainline sections with poor vision conditions (GoA 0-1) **GAF-04** - OD & TID use for freight train operating on mainline sections with specific hazards – constructions sites (GoA 0-1)	
Low-medium	**FS-03** - OD & TID use for freight train operating on shunting yard or similar controlled environment (GoA 0-1)	Main interface would be a driver HMI, interface with ATP might be more complex depending on overall system architecture and division of responsibilities for decision making (in OD & TID, ATP, Yard Management System, etc.). In any case, likely to be an onboard and trackside sensor system using different types of camera and supporting technologies (trackside only might be sufficient). The complexity may be increased due to need to ensure compatibility (as standardisation may be less/different than on mainline), and/or due to complex hazards in yards (e.g., staff and loading equipment close to trains).

6.3 Likelihood of implementation in the future

The likelihood of future implementation was evaluated considering the system's characteristics, the bottlenecks related to the development gap between the current and required technologies, interface constraints, and system requirements. Furthermore, the possibility of commercialisation and exploitation in near future was assessed. The conclusion regarding technical feasibility is generally similar for all use cases, i.e., it is feasible to resolve the constraints to implementation of OD & TID system, however, the commercialisation and exploitation depends on different factors that are specific for each UC (e.g., timescale for ATO implementation by IM and RU, development of standards for ATO under ERTMS/ETCS, etc.).

The complexity for the GoA 0-1 use cases is generally lower than the equivalent GoA 2-4 use cases, therefore, it could be considered more likely that implementation would occur in the future and the timescales for implementation might be shorter for GoA 0-1 use cases. However, the benefits and relative necessity of the OD & TID system is lower in these use cases, so the incentives and business case for implementation might be lower. Considering the overall priorities of national and international rail networks, it is foreseen that implementation of ATO, which is expected to include some form of OD & TID system, would be of a higher priority than implementation of an OD & TID only as a driver assistance system for GoA 0-1 operation. Therefore, it is plausible that, although the implementation of a OD & TID system for GoA 0-1 use cases is less complex, the increased incentives and drivers for implementation of a OD & TID system as part of an ATO system would, along with the general drive towards implementation of ATO, would make it possible that the implementation of the OD & TID systems for GoA 2-4 use cases is the more likely scenario, despite the increased complexity.

The other main distinguishing factor between the use cases with regard the likelihood of implementation, besides GoA, is the distinction between mainline and yard operations. It is expected that both ATO and OD & TID systems would be implemented for mainline operations before being implemented for yard operations, due to the greater expected benefits, in terms of increased capacity and reduction of risks and consequences of collisions.

The use cases related to the operation of long freight trains are unlikely to be implemented as a standalone use case, just for the operation of long freight trains. Therefore, their effect on the likelihood of implementation of OD & TID systems is to marginally increase the incentive for implementation of OD & TID for the other general and freight specific use cases, with the long freight train use case as an extension of the general use case (which might affect the specification of the OD & TID system, to cover all use cases). This is due to the increase in the obtained benefits from the implementation of the OD & TID in these use cases, in terms of reduction of risk, due to the particular characteristics and hazards of operating long freight trains.

In summary, the implementation of an OD & TID system is possible and is a potential enabler of increasing the GoA of railway operations, therefore, it is very likely that constraints pertaining to different actors and stakeholders will be resolved in the near future, to enable commercialisation and exploitation of OD & TID systems.

6.4 Relevance of SMART2 concept to the different use cases

The relevance of the proposed SMART2 OD & TID system concept and the specific foreseen functions of the system has been evaluated for each use case considering the role of the OD & TID system in the whole system of railway operation. In some of the use cases, the OD & TID system can significantly improve the performance of railway operation, overcome the drawbacks and mitigate the risks in the scenarios of the use case, therefore, the relevance was evaluated as ***high***. Whereas, in other use cases it is less certain that the functions of SMART2 OD & TID concept would deliver and provide a substantial contribution, therefore, the relevance level was estimated as ***potential***. It was evaluated that the SMART2 OD & TID system would be of either high or potential relevance to all use cases, and that in none of the use cases would it be considered completely irrelevant. Therefore, it is expected that the proposed SMART2 OD & TID system would be designed, tested and validated for selected use cases that have been evaluated as highly relevant. However, whilst the proposed SMART2 OD & TID system might be potentially relevant to use cases other than the selected ones, it is expected it might need further development (outside the scope of SMART2) to be implemented in that use case. The estimated relevance level is summarised below.

Table 4: Estimated relevance of SMART2 concept to the different use cases

Relevance of SMART2 concept	Use case	Justification
High	**GAF-01** - OD & TID use for freight train operating on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1) **GAF-02** - OD & TID use for freight train operating on mainline sections with poor vision conditions (GoA 0-1) **GAF-03** - OD & TID use for freight train operating on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1) **GAF-04** - OD & TID use for freight train operating on mainline sections with specific hazards – constructions sites (GoA 0-1) **GAF-05** - OD & TID use for all conventional ATO trains on mainline (GoA 2-4) **FS-01** - OD & TID use for freight trains with long stopping distance operating on mainline (GoA 0-1) **FS-02** - OD & TID use for/in freight train with long stopping distance operating on mainline (GoA 2-4)	• The SMART2 OD & TID concept would significantly reduce the risks in these UCs. • Although development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS and in GoA 2-4 grade, there is still a potential benefit in the operations on mainline in GoA 0-1 use cases and can be important for degraded mode of ETCS or last mile traffic. • Regarding GAF-04 and the aspects of this use case relating to the detection of obstacles and track intrusions on active mainlines **passing** construction sites, this is largely similar to other use cases for OD & TID systems, therefore theses aspects relating to construction sites have high relevance to SMART2.
Potential	**GAF-04** - OD & TID use for freight train operating on mainline sections with specific hazards – constructions sites (GoA 0-1) **GAF-06** - OD & TID use for all ATO trains on marshalling yard, depot, or similar controlled environment (GoA	• The SMART2 OD & TID concept has potential relevance to the OD & TID functions necessary in yard operations, and **within** construction sites, in that its sensors and processing could be adapted for this use case. However, development of

	2-4) **FS-03** - OD & TID use for freight train operating on shunting yard or similar controlled environment (GoA 0-1)	the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS, and operations in yard or construction site areas are not within the focus of SMART2. • Regarding GAF-04 and the aspects of this use case relating to the detection of obstacles and track intrusions **within** construction sites is only of potential relevance to SMART2, as the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS, not trains operating **in** construction sites. • One significant issue is that the development of ATO for mainlines is more developed than for yards, therefore, the structure of the ATO yard, as well as the role of OD & TID systems are even more uncertain.

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Appendices

A1. Use Case GAF-01: Operation on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)

<table>
<tr><td>Name:</td><td colspan="3">OD & TID use for freight train operating on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)</td></tr>
<tr><td>ID:</td><td colspan="3">OTID-UC-GAF-01</td></tr>
<tr><td>Actual Scenario</td><td colspan="3">Freight train (or locomotive) operating on mainline with reduced visibility due to temporary environmental conditions (GoA 0-1)</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="3">An OD & TID system (on driving unit/locomotive and/or trackside) supporting operation of freight trains on mainline with Grade of Automation (GoA) 0 or 1 to detect objects that are hidden from the drivers view or are unclear due to weather, accidental natural issues, etc.
The OD & TID system classifies the object and estimates its location, and this, or other systems, passes the information to driver, ATP and/or Traffic Management System (TMS).</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td colspan="2">Train operators,
Mainline Infrastructure Manager</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td colspan="2">Train operators, Mainline Infrastructure Manager
Freight service customers</td></tr>
<tr><td>Other interested parties</td><td colspan="2">Safety and investigation bodies</td></tr>
<tr><td>Frequency of use</td><td colspan="3">Daily regular use for all train journeys, particularly for occasions with temporary environmental conditions (weather, lighting conditions, natural issues such as vegetation, etc.)</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Locomotive equipped for GoA 0-1 system compatible with mainline operating system.
OD & TID system compatible with locomotive, ATP, and/or TMS.
OD & TID system capable of detecting hazards in common visibility reducing environmental conditions.</td></tr>
<tr><td rowspan="3">Typical use case implementation</td><td>Actor (party involved)</td><td>Action</td><td>System response</td></tr>
<tr><td>Locomotive driver
Locomotive operator
Infrastructure Manager (trackside OD & TID)</td><td>A1: OD & TID system detects hazard and passes information to locomotive OD & TID system HMI.</td><td>SR1: Driver views information on HMI and uses judgement to determine and implement response to hazard.</td></tr>
<tr><td>Infrastructure Manager (trackside OD & TID)
Locomotive driver</td><td>A2: Trackside OD & TID detects hazard(s) on the track or within the railway property boundary, and</td><td>SR2: Driver views information on HMI and uses judgement to determine and implement</td></tr>
</table>

	Locomotive operator	passes information to (i) locomotive OD & TID system, (ii) ATP interface, or (iii) TMS	response to hazard, and/or (i) OD & TID system makes decision and sends instruction to ATP, (ii) ATP makes decision, or (iii) TMS makes decision and triggers ATP.
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A3: OD & TID system (locomotive and/or trackside elements) detects NO hazard relevant to the path of the train and passes information to locomotive OD & TID system HMI	SR3: Driver views information on HMI continues to observe for hazards
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A4: (GoA 1 only) OD & TID system (locomotive and/or trackside elements) detects hazard and passes information to (i) locomotive OD & TID system, (ii) ATP interface, or (iii) TMS	SR4: ATP not triggered.
Post-conditions	No Hazard detected: Train continues in normal operation Hazard detected: Appropriate response implemented (e.g., sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train diverted past hazard. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Train continues to run as scheduled with a possible delay due to speed reduction. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from TMS. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become "active" as requested as train approaches and inactive after train(s) pass.		

	• Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with locomotive control system and traffic management **Risks:** • Failure of the OD & TID system can lead to the driver (and/or ATP for GoA 1) not receiving the information necessary to respond to the hazard adequately • Failure of the OD & TID system could lead to degraded mode working on sections of track affected by failure, with extra precautions due to lack of risk/hazard mitigation provided by OD & TID system • Driver could become complacent and less observant due to support from OD & TID system. • OD & TID system functional but fails to detect a particular hazard and driver does not respond to the hazard adequately • OD & TID system functional but classifies hazards too high and leads to unnecessary delay and traffic congestion **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management
Estimated priority	**Safety: medium priority** (use of OD & TID decision support systems decreases the risks and reduces the possibility of human error but the most important safety element is still driver) **Reliability and Availability: medium priority** (OD & TID decision support systems with safety function must have appropriate availability and reliability); **Maintainability: high priority** (main benefits of GoA 0-1 is increase of operational efficiency and reduced risks, therefore, OD & TID should be easy to maintain to minimise disruption in the event of a failure and system overheads); **Business: medium priority** (use of OD & TID systems will decrease all risks and therefor increase business results).
Assumptions and open issues	Uncertainty regarding system architectures, responsibilities, procedures, and, in case of GoA 1, responsibilities for triggering ATP. Also, uncertainty regarding requirements for level of hazard detection and response (would no coverage be treated as stop/slow/caution hazard detected or as no hazard detected).
Conclusion	Overall priority/importance of implementing the UC: • Overall priority is Medium due to low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and high probability of scenario occurrence. Estimation of complexity of OD & TID system for the UC: • The design of the OD & TID system and interfaces is of Medium complexity, most likely an onboard sensor system using different types of camera and supporting technologies. The interface is via driver with some relatively simple interface to ATP; interface with TMS would be more complex.

	Likelihood of implementation in the future: - Considering the actual requirements of TMS and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the near future; however, implementation of OD & TID system might occur along with increasing grade of automation. Relevance of SMART2 concept to use case - The SMART2 OD & TID concept has high relevance to the OD & TID functions necessary in conditions with reduced visibility due to temporary environmental conditions. OD & TID concept would significantly reduce the risks on sections with reduced visibility in GoA 0-1 mode. - Although development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS and in GoA 2-4 grade, there is still a potential benefit in the operations on mainline in GoA 0-1 use case and can be important for degraded mode of ETCS or last mile traffic.

A2. Use Case GAF-02: Operation on mainline sections with poor vision conditions (GoA 0-1)

Name:	OD & TID use for freight train operating on mainline sections with poor vision conditions (GoA 0-1)		
ID:	OTID-UC-GAF-02		
Actual Scenario	Freight train (or locomotive) operating on mainline sections with poor vision conditions (GoA0-1)		
Scope & Brief Description	An OD & TID system (on driving unit/locomotive and/or trackside) supporting operation of freight trains on mainline with Grade of Automation (GoA) 0 or 1 to detect objects that are hidden from the drivers view or are unclear in situations where there can be vision issues for a driver, like operation in tunnels, stations, night-time conditions. An OD & TID system classifies the object and estimates its location, and this, or other systems, passes the information to driver, ATP and/or Traffic Management System (TMS).		
Stakeholders involved (actors)	**Responsible to implement the use case (primary system actors)**	Train operators, Mainline infrastructure Manager	
	End-users/ Beneficiaries (primary business actors)	Train operators, Mainline infrastructure Manager Freight service customers	
	Other interested parties	Safety and investigation bodies	
Frequency of use	Daily, in situations with vision issues like operation in tunnels, stations, night-time conditions		
Pre-conditions	Locomotive equipped for GoA 0-1 system compatible with mainline operating system. OD & TID system compatible with locomotive, ATP, and/or TMS. OD & TID system capable of detecting hazards in common situation where drivers might have vision issues.		
ypical use case implementation	**Actor (party involved)**	**Action**	**System response**
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A1: OD & TID system detects hazard and passes information to locomotive OD & TID system HMI.	SR1: Driver views information on HMI and uses judgement to determine and implement response to hazard.
	Infrastructure Manager (trackside OD & TID) Locomotive driver Locomotive operator	A2: GoA 0-1, Trackside OD & TID detects hazard(s) on the track or within the railway property boundary, and passes information to (i) locomotive OD & TID system,	SR2: Driver views information on HMI and uses judgement to determine and implement response to hazard, and/or (i) OD & TID system makes

		(ii) ATP interface, or (iii) TMS	decision and sends instruction to ATP, (ii) ATP makes decision, or (iii) TMS makes decision and triggers ATP.
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A3: OD & TID system (locomotive and/or trackside elements) detects NO hazard relevant to the path of the train and passes information to locomotive OD & TID system HMI	SR3: Driver views information on HMI continues to observe for hazards
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A4: (GoA 1 only) OD & TID system (locomotive and/or trackside elements) detects hazard and passes information to (i) locomotive OD & TID system, (ii) ATP interface, or (iii) TMS	SR4: ATP not triggered.
Post-conditions	No Hazard detected: Train continues in normal operation Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train diverted past hazard. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Train continues to run as scheduled with a possible delay due to speed reduction. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from TMS. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become “active” as requested as train approaches and inactive after train(s) pass. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.		

Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with locomotive control system and traffic management **Risks:** • Failure of the OD & TID system can lead to the driver (and/or ATP for GoA 1) not receiving the information necessary to respond to the hazard adequately • Failure of the OD & TID system could lead to degraded mode working on sections of track affected by failure, with extra precautions due to lack of risk/hazard mitigation provided by OD & TID system • Driver could become complacent and less observant due to support from OD & TID system. • OD & TID system functional but fails to detect a particular hazard and driver does not respond adequately to the hazard • OD & TID system also adversely affected in its ability to detect hazard by adverse lighting conditions (e.g. high contrast areas, glare from sun/lights) • OD & TID system functional but classifies hazards too high and leads to unnecessary delay and traffic congestion **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management
Estimated priority	**Safety: medium priority** (use of OD & TID decision support systems decreases the risks and reduces the possibility of human error but the most important safety element is still driver) **Reliability and Availability: medium priority** (OD & TID decision support systems with safety function must have appropriate availability and reliability); **Maintainability: high priority** (main benefits of GoA 0-1 is increase of operational efficiency and reduced risks, therefore, OD & TID should be easy to maintain to minimise disruption in the event of a failure and system overheads); **Business: medium priority** (use of OD & TID systems will decrease all risks and therefore increase business results).
Assumptions and open issues	Uncertainty regarding system architectures, responsibilities, procedures, and, in case of GoA 1, responsibilities for triggering ATP. Also, uncertainty regarding requirements for level of hazard detection and response (would no coverage be treated as stop/slow/caution hazard detected or as no hazard detected).
Conclusion	<u>Overall priority/importance of implementing the UC:</u> • Overall priority is Medium due to low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and high probability of scenario occurrence. <u>Estimation of complexity of OD & TID system for the UC:</u> • The design of the OD & TID system and interfaces is of Medium complexity, most likely an onboard sensor system using different types of camera and supporting technologies, and interface is via driver with some relatively simple interface to ATP. The complexity may increase if additional trackside elements would be required, and/or if interfacing with TMS.

	<u>Likelihood of implementation in the future:</u> • Considering the actual requirements of TMS and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the near future; however, implementation of OD & TID might occur along with increasing grade of automation. <u>Relevance of SMART2 concept to use case</u> • The SMART2 OD & TID concept has high relevance to the OD & TID functions necessary in conditions with vision issues like tunnel, stations or night-time conditions. OD & TID concept would significantly reduce the risks on sections with vision issues. • Although development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS and in GoA 2-4 grade, there is still a potential benefit in the operations on mainline in GoA 0-1 use case and can be important for degraded mode of ETCS or last mile traffic.

A3. Use Case GAF-03: Operation on mainline sections with specific hazards - reduced visibility due to permanent causes (GoA 0-1)

<table>
<tr><td>Name:</td><td colspan="3">OD & TID use for freight train operating on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1)</td></tr>
<tr><td>ID:</td><td colspan="3">OTID-UC-GAF-03</td></tr>
<tr><td>Actual Scenario</td><td colspan="3">Freight train operating on mainline sections with specific hazards – reduced visibility due to permanent causes (GoA 0-1)</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="3">An OD & TID system (on driving unit/locomotive and/or trackside) supporting operation of freight trains on mainline with Grade of Automation (GoA) 0 or 1 to detect objects that are hidden from the drivers view due to permanent causes.
An OD & TID system classifies the object and estimates its location, and this, or other systems, passes the information to driver, ATP and/or Traffic Management System (TMS).</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td colspan="2">Mainline Infrastructure Manager, Train operators,</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td colspan="2">Locomotive operators, Mainline Infrastructure Manager
Freight service customers</td></tr>
<tr><td>Other interested parties</td><td colspan="2">Safety and investigation bodies</td></tr>
<tr><td>Frequency of use</td><td colspan="3">Daily, in situations on mainline sections with specific hazards – reduced visibility due to permanent causes (e.g., due to tight curves, structures or dense and high vegetation close to the track, etc).</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Locomotive equipped for GoA 0-1 system compatible with mainline operating system.
OD & TID system capable of detecting hazards in path of train but out of line of sight of front of train (view obstructed) and communicating that detection to train control system (driver, ATP, TMS).</td></tr>
<tr><td rowspan="3">Typical use case implementation</td><td>Actor (party involved)</td><td>Action</td><td>System response</td></tr>
<tr><td>Locomotive driver
Locomotive operator
Infrastructure Manager (trackside OD & TID)</td><td>A1: OD & TID system detects hazard and passes information to locomotive OD & TID system HMI.</td><td>SR1: Driver views information on HMI and uses judgement to determine and implement response to hazard.</td></tr>
<tr><td>Infrastructure Manager (trackside OD & TID)
Locomotive driver
Locomotive operator</td><td>A2: Trackside OD & TID detects hazard(s) on the track or within the railway property boundary, and passes information to (i) locomotive OD & TID system, (ii) ATP interface, or (iii) TMS</td><td>SR2: Driver views information on HMI and uses judgement to determine and implement response to hazard, and/or (i) OD & TID system makes decision and sends instruction to ATP, (ii) ATP</td></tr>
</table>

			makes decision, or (iii) TMS makes decision and triggers ATP.
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A3: OD & TID system (locomotive and/or trackside elements) detects NO hazard relevant to the path of the train and passes information to locomotive OD & TID system HMI	SR3: Driver views information on HMI continues to observe for hazards
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A4: (GoA 1 only) OD & TID system (locomotive and/or trackside elements) detects hazard and passes information to (i) locomotive OD & TID system, (ii) ATP interface, or (iii) TMS	SR4: ATP not triggered.
Post-conditions	No Hazard detected: Train continues in normal operation Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train diverted past hazard. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Train continues to run as scheduled with a possible delay due to speed reduction. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from TMS. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become “active” as requested as train approaches and inactive after train(s) pass. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.		
Implementation	**Constraints:**		

constraints, risks and requirements	• OD & TID system must be compatible with locomotive control system and traffic management **Risks:** • Failure of the OD & TID system can lead to the driver (and/or ATP for GoA 1) not receiving the information necessary to respond to the hazard adequately • Failure of the OD & TID system could lead to degraded mode working on sections of track affected by failure, with extra precautions due to lack of risk/hazard mitigation provided by OD & TID system • Driver could become complacent and less observant due to support from OD & TID system. • OD & TID system functional but fails to detect a particular hazard and driver not able to respond adequately to the hazard due to blocked view of the hazard and operation (e.g. speed) based on hazards being detected. • OD & TID system functional but classifies hazards too high and leads to unnecessary delay and traffic congestion **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management
Estimated priority	**Safety: medium priority** (use of OD & TID decision support systems decreases the risks and reduces the possibility of human error but the most important safety element is still driver) **Reliability and Availability: medium priority** (OD & TID decision support systems with safety function must have appropriate availability and reliability); **Maintainability: high priority** (main benefits of GoA 0-1 is increase of operational efficiency and reduced risks, therefore, OD & TID should be easy to maintain to minimise disruption in the event of a failure and system overheads); **Business: medium priority** (use of OD & TID systems will decrease all risks and therefor increase business results).
Assumptions and open issues	Uncertainty regarding system architectures, responsibilities, procedures, and, in case of GoA 1, responsibilities for triggering ATP. Also, uncertainty regarding requirements for level of hazard detection and response (would no coverage be treated as stop/slow/caution hazard detected or as no hazard detected).
Conclusion	<u>Overall priority/importance of implementing the UC:</u> • Overall priority is Medium due to low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and high probability of scenario occurrence. <u>Estimation of complexity of OD & TID system for the UC:</u> • The design of the OD & TID system and interfaces is of Medium-high complexity, most likely a fusion/combination of inputs from an onboard sensor system and trackside elements using different types of camera and supporting technologies. The interface is via driver with some relatively simple interface to ATP; interface with TMS would be more complex. <u>Likelihood of implementation in the future:</u> • Considering the actual requirements of TMS and status of technology

	developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the near future; however, implementation of OD & TID might occur along with increasing grade of automation. Relevance of SMART2 concept to use case • The SMART2 OD & TID concept has high relevance to the OD & TID functions necessary in conditions with reduced visibility due to permanent causes. OD & TID concept would significantly reduce the risks on sections with reduced visibility due to permanent causes, or enable more efficient operation (e.g. higher speeds, removal of visibility related speed restrictions) because the risks are being mitigated by the OD & TID system. • Although development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS and in GoA 2-4 grade, there is still a potential benefit in the operations on mainline in GoA 0-1 use case and can be important for degraded mode of ETCS or last mile traffic.

A4. Use Case GAF-04: Operation on mainline sections with specific hazards - constructions sites (GoA 0-1)

<table>
<tr><td>Name:</td><td colspan="2">OD & TID use for freight train operating on mainline sections with specific hazards – constructions sites (GoA 0-1)</td></tr>
<tr><td>ID:</td><td colspan="2">OTID-GAF-04</td></tr>
<tr><td>Actual Scenario</td><td colspan="2">Freight train (or locomotive) operating on mainline sections with specific hazards - constructions sites, in GoA 0-1 conditions.</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="2">An OD & TID system (onboard/airborne/or trackside) might be required for operating freight trains GoA 0 or 1 close to (or into) construction/maintenance sites to detect potential obstacles on the track or close to the path of the train, so that the processed information may be used by the train control system to determine the safe extent of movement and inform the parties involved.
• Freight train in ETRMS/ETCS area (on mainline) close to construction/maintenance sites
• Train operating with GoA 0-1 past/in construction/maintenance site
• OD & TID system(s) used to supervise the safe movement of trains near construction/maintenance sites, might also include detection and classification of objects in some <u>location-based scenarios</u>:
  ○ detection and classification of the construction/maintenance site objects in case of in case of possession of adjacent track near construction/maintenance sites
  ○ detection and classification of the construction/maintenance site objects in case of a possession on a straight section of track (or section with sufficient line of sight ahead of the train)
  ○ detection and classification of the construction/maintenance site objects in case of construction/maintenance work on areas blocking trains' view
  ○ detection and classification of the construction/maintenance site objects in case of level crossing possession
The function of the OD & TID system is the same in <u>plan-based scenarios</u>, but the role of it is different. Specific role in these scenarios include:
• detection and classification of the construction/maintenance site objects in case of planned activities
• detection and classification of the construction/maintenance site objects in case of emergency engineering activities
• detection and classification of the construction/maintenance site objects after track possession due to activities ends</td></tr>
<tr><td rowspan="2">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td>Locomotive operators,
Infrastructure manager (trackside OD & TID)
Infrastructure manager (TMS)
Infrastructure manager (maintenance/construction works)</td></tr>
<tr><td>End-users/ Beneficiaries
(primary business actors)</td><td>Locomotive operators
Railway operators
Freight service customers</td></tr>
</table>

	Other interested parties	Engineering Supervisors Mainline Infrastructure Manager Construction/maintenance companies	
Frequency of use	• Planned construction/maintenance: frequency depends on routine and daily, weekly, annually construction/maintenance activities • Emergency engineering construction/maintenance: frequency is uncertain due to occurrence of urgent need for repair or maintenance		
Pre-conditions	• Functionality of all OD & TID systems and sub systems • Continuous communication between OD & TID systems, vehicle and the key actors (locomotive operator, OD & TID systems, ATP, TMS). • Compatibility between systems (OD & TID, driver HMI, ATP, TMS)		
Typical use case implementation	**Actor (party involved)**	**Action**	**System response**
	OD & TID system operator (loco operator)	A1: OD & TID system detects hazard, driver is informed on HMI (e.g. enhanced image of hazard) and responds	SR1: OD & TID system detects hazard, hazard detection passed to HMI
	OD & TID system operator (loco operator)	A2: (GoA 1 only) OD & TID system detects critical hazard (immediate risk to train)	SR2: OD & TID system detects hazard, hazard detection passed decision system, ATP stops train
	OD & TID system operator (loco operator)	A3: OD & TID system detects no hazards relevant to a movement,	SR3: OD & TID system and passes clear signal to Driver HMI/TMS/ATP
	OD & TID system operator (loco operator, signaller)	A4: OD & TID system detects hazards on route ahead of train(s) relevant to their movement, a route diversion is possible	SR4: OD & TID system and passes information to TMS, TMS diverts train(s) to alternate route.
Post-conditions	No Hazard detected: Train continues in normal operation (past/into construction/maintenance site) Hazard detected: Appropriate response implemented (e.g., sound audible warning, slow or stop train, or emergency procedures), train passes hazard (or construction/maintenance site) safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Entity responsible for works in site informed and take appropriate action. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised		
Post-use Scenario	Train perspective: • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train		

	diverted past hazard. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Train continues to run as scheduled with a possible delay due to speed reduction. • End of service: Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from TMS. OD & TID system perspective: • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become “active” as requested as train approaches and inactive after train(s) pass. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed. Infrastructure manager/TMS perspective: • Detected hazards: (staff/equipment/materials exceeding possession/work area and posing hazard to trains on adjacent tracks, OR equipment/material left on/near track after completion of work): Hazard removed before possession lifted. • No hazard detected: Route considered clear for further trains
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with the form of train control and traffic management system **Risks:** • Loss of communication between specific OD & TID systems and involved actors and parties, as well as risks occurring due to objects and intrusion, this loss could cause more risks and hazards for train operation • Single failure of specific OD & TID systems (onboard/airborne/trackside) in critical area could prevent or restrict all operations if it creates a gap in the detection coverage and there is no redundancy • Security vulnerability of safety critical wireless communication for OD & TID **Requirements:** • Must be cross compatibility between HMI of the OD & TID system, the form of train control, and traffic management system
Estimated priority	For Location-Based Scenario: Straight section of track (or section with sufficient line of sight ahead of the train), level crossing, and adjacent track possession - ***Low priority*** because: • Locomotive operator still has main train control role and current procedures capable of performing operations For Location-Based Scenario: Construction/maintenance site on areas blocking trains’ view - ***Medium-High priority*** because: • Locomotive operator has limited main train control role and current procedures capable of performing operations For Plan-Based Scenario: Planned activities, when track possession ends - ***Low priority*** because: • Locomotive operator is informed about the planned construction/maintenance

	activity so can be alert for potential hazards • Entity in charge of works has responsibility for ensuring site safe for passage of trains before lifting possession – OD & TID should only be a backup system in case something is missed. For Plan-Based Scenario: Emergency engineering construction/maintenance scenario - ***Medium-High*** priority because: • Locomotive operator might not be informed about the construction/maintenance activity therefore high risk of incident without OD & TID system to detect the potential hazards
Assumptions and open issues	Main assumption is the continuous communication between key actors and OD & TID system/subsystems. Loss or a gap in this communication can cause interruption in ATP and traffic management procedures.
Conclusion	<u>Overall priority/importance of implementing the UC:</u> • Overall priority is Medium-Low due to low-medium impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could improve safety) and moderately high probability of scenario occurrence. Priority for trains passing work sites is probably higher than trains entering work sites, since trains in work sites run at reduced speed (ROS). <u>Estimation of complexity of OD & TID system for the UC:</u> • The design of the OD & TID system and interfaces is of Medium complexity, most likely an onboard sensor system using different types of camera and supporting technologies, and interface is via driver with some relatively simple interface to ATP. The complexity may increase if additional trackside elements would be required, and/or if interfacing with TMS. <u>Likelihood of implementation in the future:</u> • Considering the actual requirements of TMS and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the near future; however, implementation of OD & TID might occur along with increasing grade of automation. <u>Relevance of SMART2 concept to use case:</u> • The SMART2 OD & TID concept has potential relevance to the OD & TID functions necessary for vehicles operating close to construction/maintenance sites, as its sensors and processing could be adapted for this use case. In location-based scenarios, the detection and classification of objects allow a safe operation in case that construction/maintenance site objects do not pose a hazard to trains in normal traffic passing on adjacent track. Furthermore, if a route diversion is possible, then based on identified risks and hazards, TMS can take necessary actions for continuous train operation. In plan-based scenarios, identification of risks and hazards is critical since locomotive operator might not be informed about this activity. Therefore, in relation to train movements in and around constructions sites, the SMART2 OD & TID concept is highly relevant to the aspects concerning trains passing the construction site in normal operation on an active mainline; however, the concept is only potentially relevant for future adaption to the operation of trains within a construction site.

A5. Use Case GAF-05 All conventional ATO trains on mainline (GoA2-4)

<table>
<tr><td>Name:</td><td colspan="3">OD & TID use for all conventional ATO trains on mainline (GoA 2-4)</td></tr>
<tr><td>ID:</td><td colspan="3">OTID-UC-GAF-05</td></tr>
<tr><td>Actual Scenario</td><td colspan="3">Typical freight trains operating on mainline (GoA 2-4)</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="3">An OD & TID system (on driving unit/locomotive and/or trackside) is required for operating freight trains on mainline with Grade of Automation (GoA) 2-4.
OD & TID system detects object intruding on the track or within the railway property boundary, classifies the object and estimates the location of the object. That information, and the location of approaching trains, is used by the automatic train control and/or TMS to implement the appropriate response.</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td colspan="2">Train operator
Traffic management</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td colspan="2">Train operators, freight customers</td></tr>
<tr><td>Other interested parties</td><td colspan="2">Secondary line and yard manager, safety and investigation bodies</td></tr>
<tr><td>Frequency of use</td><td colspan="3">Daily - continuously throughout the journeys of every freight train/loco on the mainline (operating with GoA 2-4)</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Locomotive with GoA 2-4 system compatible with ERTMS/ECTS.
Line equipped with ERTMS/ECTS
Locomotive and/or trackside equipped with OD & TID system
Compatibility between detection, train control and TMS systems
Sufficient operational OD & TID equipment to meet minimum detection coverage defined for system.</td></tr>
<tr><td rowspan="2">Typical use case implementation</td><td>Actor (party involved)</td><td>Action</td><td>System response</td></tr>
<tr><td>Locomotive operator
TMS
Infrastructure Manager (trackside OD & TID)
Driver/attendant (GoA 2-3)</td><td>A1: (GoA 2-4) OD & TID system detects hazard and passes information to (i) TMS, and/or (ii) control system of approaching locomotive.
(GoA 2-3 only) Detection also displayed on locomotive OD & TID system HMI for information of supervising driver/attendant (where present).</td><td>SR1: (GoA 2-4) (i) TMS modifies movement authority/target motion profile for affected trains accordingly and communicates to train control, and/or (ii) train control reacts to hazards.
(GoA 2-3 only) Driver/attendant views information on HMI and uses judgement to determine and implement response to hazard if necessary.</td></tr>
</table>

	Locomotive operator TMS Infrastructure Manager (trackside OD & TID) Driver/attendant (GoA 2-3)	A2: (GoA 2-4) OD & TID system detects NO hazard and passes information to (i) TMS, and/or (ii) control system of approaching locomotive. (GoA 2-3 only) Detection also displayed on locomotive AOD & TID system HMI for information of supervising driver/attendant (where present).	SR2: (GoA 2-4) (i) TMS modifies movement authority/target motion profile and communicates to train control, and/or (ii) train control reacts to hazards. (GoA 2-3 only) Driver/attendant views information on HMI at intervals/as necessary and continues to monitor for hazards or carry out other duties.
	Infrastructure Manager TMS	A3: (GoA 2-4) OD & TID system detects hazard and passes information to TMS.	SR3: TMS (in addition to actions related to movement of trains) informs Infrastructure manager (IM), IM arranges for hazard to be removed or other appropriate response. Depending of type of obstacle/object, TMS might suspend services on track at location (or divert trains around affected location) and modify movement authority of trains in the region accordingly.
Post-conditions	No Hazard detected: Train continues in normal operation. Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA2-3, driver/attendant might override ATO or hazard detection to continue past hazard before returning to normal operation. Hazard detected: Train diverted to alternate route by TMS and continues. The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised.		
Post-use Scenario	Train continues to run as scheduled with a possible delay due to speed reduction. After stopping the driver or attendant and/or traffic control take the prescribed procedures and measures to eliminate the obstacle or divert the train to the alternative track. After the collision, the driver, escort and/or traffic control take appropriate procedures and measures in case of emergency. <u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Normal operation: Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 2-		

	3, driver/attendant input might be required to assess hazard and instruct/override train control and continue past hazard before returning to normal operation. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer receiving movement authority/target motion profile from TMS or communicating with OD & TID system. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications to TMS, OR elements become “active” as requested as train approaches and inactive after train(s) pass. In case of system architecture where elements are switched between active and inactive, switching could be controlled by request/information from TMS or communication with approaching trains. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed. <u>Infrastructure Manager perspective:</u> • Hazard detected: Obstacle investigated/removed, or intrusion investigated (repair fences etc.) as appropriate.
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with ERTMS/ECTS and train control system; • There must be sufficient operational OD & TID equipment to meet minimum detection coverage defined for system; • In GoA 4 mode OD & TID system must be capable for meeting safety requirements for traffic in degraded mode. **Risks:** • Single failure of trackside OD & TID system in critical area could prevent or restrict all operations in mainline if it creates a gap in the detection coverage and there is no redundancy; • Security vulnerability of safety critical wireless communication for OD & TID; • OD & TID system functional but fails to detect a particular hazard; • (GoA 2) Driver could become complacent and less observant due to automation and lack of involvement in train operation; • (GoA 3-4) No human backup in case of system failure or local observation/supervision/intervention in case of system performing unsafe actions; • Emergency braking in some situations could lead to derailment. This hazard may be greater than the hazard of collision with small obstruction; • OD & TID system functional but false positives or classifies/miss-identifies hazards as too high a risk, resulting in unnecessary delays to service. **Requirements:** • Must be cross compatibility between OD & TID system and ERTMS/ECTS.
Estimated priority	**Safety: high priority** (although the risk is lower than that of passenger trains, the collision between obstacle and a freight train on the main line can have catastrophic consequences, especially if it involves the transport of dangerous goods); **Reliability and Availability: high priority** (OD & TID systems with safety critical

	function must have high availability and reliability to avoid service disruption); **Maintainability: high priority** (main benefits of GoA 3-4 is increase of operational efficiency and reduced costs, therefore, OD & TID should be easy to maintain to minimise disruption in the event of a failure and system overheads);
Assumptions and open issues	There are no clear rules and procedures for full automation traffic (GoA 4 mode) in ERTMS/ECTS degraded mode or emergency situations
Conclusion	Overall priority/importance of implementing the UC: • Overall priority is Very High since some form of OD & TID would almost certainly be required as input to automated train control to make risks of ATO acceptable for national/international networks; therefore, OD & TID would be in continuous use. Estimation of complexity of OD & TID system for the UC: • The design of the OD & TID system and interfaces would be of High-Medium complexity, depending on overall ATO system architecture and division of responsibilities for decision making (in OD & TID, ATC, TMS, etc.). In any case, likely to be an onboard and trackside sensor system using different types of camera and supporting technologies, with interface to other ATO systems (ATC, TMS, etc.) and interface to driver/attendant HMI (either direct or from another system, e.g. TMS). Likelihood of implementation in the future: • Considering the actual requirements of TMS, expected reliance of ATO on OD & TID, and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the medium-longer term future (depending on timescale for ATO implementation by IM and RU, in general, and development of standards for ATO under ERTMS/ETCS). Relevance of SMART2 concept to use case • The SMART2 OD & TID concept is focused on mainlines controlled by ERTMS/ETCS, therefore, this use case is highly relevant for further development of the system. It is estimated that the potential use of the SMART2 system will have a significant impact on future implementation of ATO at GoA 2-4.

A6. Use Case GAF-06: All ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-4)

<table>
<tr><td>Name:</td><td colspan="2">OD & TID use for all ATO trains on marshalling yard, depot, or similar controlled environment (GoA 2-4)</td></tr>
<tr><td>ID:</td><td colspan="2">OTID-UC-GAF-06</td></tr>
<tr><td>Actual Scenario</td><td colspan="2">All trains and motive power operating in a yard (freight trains, empty passenger trains or locomotives) operating on shunting yard or similar controlled environment (GoA 2-4). The OD & TID system use is similar for all types of trains, including the freight ones.
Typical scenario would be a centrally coordinated and managed automated yard where all locomotives (includes passenger/freight multiple units) movements and placing of vehicles is controlled by a yard management system giving movement instructions and authority to locomotives operating under autonomous control. The OD & TID system could be detecting hazards and communicating it to the locomotive control system and/or the yard management system to supervise the safety of the movements. The yard OD & TID system could use the same technology and interfaces as the mainline or a dedicated system suited to the requirements of yard operation.</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="2">Non-ERTMS/ETCS conditions (no specific movement authority).
Motive power being operated autonomously under GoA 2-4, including:
yards where autonomous independent locomotive operation (where locomotive operator can specify loco movement independently, without other system), and
automated yards (yards where movements are carried out by ATO and directed by automated yard management system).
Supervision of movement (check clear of obstructions) in yard areas, might also include:
detection and range finding (or detection and exemption under specific conditions) of vehicles intended to make contact with (coupling);
detecting route set;
detecting location reference points (e.g. loading zone).</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td>Locomotive/train operator and yard management</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td>Train operators, freight customers</td></tr>
<tr><td>Other interested parties</td><td>Passengers (interest in trains arriving into service from yards)</td></tr>
<tr><td>Frequency of use</td><td colspan="2">Daily – Start and end of most passenger trains period of operation, start, end and some calling points of every freight train/loco journey</td></tr>
<tr><td>Pre-conditions</td><td colspan="2">Locomotive/train not in an ERTMS/ETCS region of the network.</td></tr>
</table>

	Locomotive equipped for ATO in yards and compatible with yard OD & TID system and/or yard management system Movement controlled by yard traffic management, or yard where non-centrally controlled ATO permitted.		
Typical use case implementation	**Actor (party involved)**	**Action**	**System response**
	Locomotive operator	A1: move between locations in yard	SR1: detect obstacles in path (possibly also objects relevant to other trains) and report to train control
	Yard train control	A2: move between locations in yard	SR2: detect obstacles in path (possibly also objects relevant to other trains) and report to train control
	Locomotive operator	A3: move into controlled contact with another vehicle	SR3: detect obstacles in path (possibly also objects relevant to other trains) and report to train control, and possibly also detect range to target vehicle and route
	Yard train control	A4: move into controlled contact with another vehicle	SR4: detect obstacles in path (possibly also objects relevant to other trains) and report to train control, and possibly also detect range to target vehicle and route
	Yard operator	A5: OD & TID in passive mode	SR5: detects and possibly tracks objects in yard area, passes detection/tracking to yard management system which logs detections (without specific reference to a train movement) for reference in case movement of train commanded/authorised.
Post-conditions	Normal operations: Yard operations continue until end of train/locomotive movement in yard in safe conditions; OD & TID system monitoring/tracking potential hazards. Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, or hazard removed/train diverted, and train moves past hazards and continues. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised.		
Post-use Scenario	Train perspective: • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train diverted past hazard. In case of GoA 2 or 3, driver/attendant might override		

	ATO or hazard detection to continue past hazard, or authorise/command ATO to pass hazard, before returning to normal operation. Yard operations continue with a possible delay. • End of yard operations; Locomotive and vehicles in required positions in the yard area - no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from yard management system. OR Loco/train assembled and awaiting movement authority to enter ERTMS/ETCS region of network. OD & TID system perspective: • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become "active" as requested as train(s) move in different area of the yard and inactive after train(s) stop or move to another area. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with the form of train control and traffic management in each yard visited **Risks:** • Single failure of trackside OD & TID system in critical area could prevent or restrict all operations in a yard if it creates a gap in the detection coverage and there is no redundancy • Security vulnerability of safety critical wireless communication for OD & TID • OD & TID system functional but fails to detect a particular hazard o No human backup in case of system failure or local observation/supervision/intervention in case of system performing unsafe actions (in GoA 2 and 3, driver/attendant, though present, might not notice failure to detect hazard as they might be occupied with other activities, or not alert due to reduced role). **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management in each yard visited • OD & TID system must be able to detect and identify common hazards, and detect all hazards, to/caused by movement of train in all conditions
Estimated priority	**Safety: medium priority** (usually low speed and no passengers on trains, therefore not highest risk; however, still risk of injury to staff, damage to assets and environmental damage, also low risk of wider impact, e.g., release of toxic/flammable/harmful cargo); **Reliability and Availability: high priority** (yard operations critical to operation of freight train, therefore OD & TID systems with safety critical function must have high availability and reliability to avoid service disruption; **Maintainability: high priority** (main benefits of GoA 2-4 is increase of operational efficiency and reduced costs, therefore, OD & TID should be easy to maintain to minimise disruption in the event of a failure and system overheads); **Business: medium priority** (i. automation of yard operations would enable full benefits of ATO to be realised; however, state of development lower than mainline,

	therefore, further from achieving benefits; ii. the implementation of ATO on mainlines might be imposed by network manager sooner, therefore, incentive for implementing OD &TID for GoA 3-4 in yards lower than for mainline)
Assumptions and open issues	Method of train control and movement instruction in yards is unclear and affects the interfaces of the OD &TID system with ATO and other systems.
Conclusion	Overall priority/importance of implementing the UC: • Overall priority is High due some form of OD & TID would almost certainly be required as input to automated train control in yards to make risks of ATO acceptable, and ATO in yards likely extension of ATO on mainlines; therefore OD & TID in yards would be required daily for most starting, calling and end points. Estimation of complexity of OD & TID system for the UC: • The design of the OD & TID system and interfaces would be of High-Medium complexity, depending on overall ATO system architecture and division of responsibilities for decision making (in OD & TID, ATC, Yard Management System, etc.). In any case, likely to be an onboard and trackside sensor system using different types of camera and supporting technologies (trackside only might be sufficient), with interface to other ATO systems and interface to driver/attendant HMI (either direct or from another system, e.g., TMS). The complexity may be increased due to need to ensure compatibility (as standardisation may be less/different than on mainline), and/or due to complex hazards in yards (e.g., staff and loading equipment close to trains). Likelihood of implementation in the future: • Considering the actual requirements of yard management system, expected reliance of ATO on OD & TID, and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the medium-longer term future (depending on timescale for ATO implementation by IM and RU, in general, and development of standards for ATO under ERTMS/ETCS). Relevance of SMART2 to use case: • The SMART2 OD & TID concept has potential relevance to the OD & TID functions necessary in yard operations, in that its sensors and processing could be adapted for this use case. However, development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS, and operations in yard areas are not within the focus of SMART2. • One significant issue is that the development of ATO for mainlines is more developed than for yards, therefore, the structure of the ATO yard, as well as the role of OD & TID systems are even more uncertain.

A7. Use Case FS-01: Freight train with long stopping distance operating on mainline (GoA 0-1)

<table>
<tr><td>Name:</td><td colspan="3">OD & TID use for freight trains with long stopping distance operating on mainline (GoA 0-1)</td></tr>
<tr><td>ID:</td><td colspan="3">OTID-FS-01</td></tr>
<tr><td>Actual Scenario</td><td colspan="3">Detection of obstacles and track intrusion in the area covering the reaction and stopping distance ahead of a Freight train with long stopping distance operating on mainline (GoA 0-1) and providing the detection information to the driver/ATP to respond accordingly.</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="3">Scope includes:
• Mainlines with trackside OD & TID systems and ATP functionality (for GoA 1), where driver operation is permitted
• Freight trains with long stopping distance controlled by driver (GoA 0)
Freight trains with long stopping distance controlled by driver where OD & TID system provides information on hazards ahead of the train to the driver (via HMI), and in case of GoA 1, ATP system, for the appropriate actions regarding train control to be take in response to the hazard.</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td colspan="2">Locomotive operators
Infrastructure managers (traffic management (for system architectures involving TMS) and trackside equipment maintenance departments)</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td colspan="2">Locomotive operators,
Yard operators
Freight service operators</td></tr>
<tr><td>Other interested parties</td><td colspan="2">Freight service customers</td></tr>
<tr><td>Frequency of use</td><td colspan="3">Daily for all mainline operations and trips of trains with long stopping distances.</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Mainline with OD & TID and communication systems
Locomotive with external OD & TID system interface installed (compatibility as below)
Compatibility and communication between trackside OD & TID system(s) and locomotive (HMI), alternatively compatibility between locomotive and relay of trackside OD & TID inputs via TMS.
Compatibility and communication between OD & TID system(s) and ATP system, alternatively compatibility between ATP and TMS (with TMS triggering ATP based on OD & TID system).</td></tr>
<tr><td rowspan="2">Typical use case implementation</td><td>Actor (party involved)</td><td>Action</td><td>System response</td></tr>
<tr><td>Locomotive driver
Locomotive operator
Infrastructure Manager (trackside OD & TID)</td><td>A1: OD & TID system detects hazard and passes information to locomotive OD & TID system HMI.</td><td>SR1: Driver views information on HMI and uses judgement to determine and implement response</td></tr>
</table>

			to hazard
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A2: (GoA 1 only) OD & TID system detects hazard and passes information to locomotive (i) OD & TID system, (ii) ATP interface, or (iii) TMS	SR2: (i) OD & TID system makes decision and sends instruction to ATP, (ii) ATP makes decision, or (iii) TMS makes decision and triggers ATP.
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A3: OD & TID system detects NO hazard relevant to the path of the train and passes information to locomotive OD & TID system HMI	SR3: Driver views information on HMI continues to observe for hazards
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A4: (GoA 1 only) OD & TID system detects hazard and passes information to locomotive (i) OD & TID system, (ii) ATP interface, or (iii) TMS	SR4: ATP not triggered.
Post-conditions	No Hazard detected: Train continues in normal operation Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation.		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from TMS. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become “active” as requested as train approaches and inactive after train(s) pass. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.		
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible mainline TMS in each area, and locomotive must be compatible with the/all OD & TID systems and TMS along route.		

	Risks: • Single failure of trackside OD & TID system in critical area could prevent or restrict all operations on mainline if it creates a gap in the detection coverage and there is no redundancy • Driver could become complacent and less observant due to support from OD & TID system. • False positives could cause unnecessary delays or reduce confidence in the system • False negatives could but train at risk • Emergency brake application by ATP could lead to derailment of freight train • Security vulnerability of safety critical wireless communication for OD & TID **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management in each yard visited
Estimated priority	**Reliability, availability & maintainability: Low priority** – Current operating system and procedure enables the operation of trains with long stopping distances, adding additional novel components interface, communication and processing requirements might reduce reliability and network/locomotive availability in the short term and increase maintenance requirements. **Safety: High priority** - trains with long stopping distance tend to be the highest risk in terms of derailment due to train handling (driver judgement used) and cargo hazard/volatility and have the greatest issues with detecting hazards within the reaction and stopping distance ahead of the train, therefore would benefit the most from assistance in detecting hazards. **Commercial: Medium/High priority** – Trains with long stopping distances are usually high revenue earners (high volume/weight of cargo), so high priority to ensure they are compatible with network requirements and can continue to operate.
Assumptions and open issues	Assumes compatibility and all systems operative are a requirement for normal operation. Uncertainty regarding system architectures, responsibilities, procedures, and, in case of GoA 1, responsibilities for triggering ATP. Also, uncertainty regarding requirements for level of hazard detection and response (would no coverage be treated as stop/slow/caution hazard detected or as no hazard detected).
Conclusion	<u>Overall priority/importance of implementing the UC:</u> • Overall priority is Medium-High due to medium-high impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, however, implementation could significantly improve safety) and medium-high probability of scenario occurrence. <u>Estimation of complexity of OD & TID system for the UC:</u> • The design of the OD & TID system and interfaces is of Medium-High complexity, most likely a fusion/combination of inputs from on onboard sensor system and trackside elements using different types of camera and supporting technologies. Interface is via driver with some relatively simple interface to ATP; interface with TMS would be more complex. <u>Likelihood of implementation in the future:</u> • Considering the actual requirements of TMS and status of technology developments, it is feasible to resolve the constraints to implementation of OD

	& TID system for this UC; therefore, commercialisation and exploitation is likely in the near future, however, implementation of OD & TID might occur along with increasing grade of automation. Relevance of SMART2 concept to use case: • The SMART2 OD & TID concept is highly relevant to this use case, as the objective of SMART2 is to extend the hazard detection distance in front of a train to up to 2km.

A8. Use Case FS-02: Freight train with long stopping distance operating on mainline (GoA 2-4)

Name:	OD & TID use for/in Freight train with long stopping distance operating on mainline (GoA 2-4)	
ID:	OTID-FS-02	
Actual Scenario	Detection of obstacles and track intrusion in the area covering the reaction and stopping distance ahead of a Freight train with long stopping distance operating on mainline (GoA 2-4) and providing the detection information to the Automatic Train Control and TMS to respond accordingly (and to provide information as supplemental information for driver/attendant depending on GoA).	
Scope & Brief Description	Scope includes: • Mainlines with trackside OD & TID systems and GoA 2-4 operation • Freight trains with long stopping distance controlled by ATO Freight trains with long stopping distance controlled by driver where OD & TID system provides information on hazards ahead of the train either direct to the GoA 2-4 train control, or as modified movement authority/target motion profile via TMS), for the train control to take appropriate actions regarding train control to be take in response to the hazard.	
Stakeholders involved (actors)	**Responsible to implement the use case (primary system actors)**	Locomotive operators Infrastructure managers (traffic management and trackside equipment maintenance departments)
	End-users/ Beneficiaries (primary business actors)	Locomotive operators, Yard operators Freight service operators
	Other interested parties	Freight service customers
Frequency of use	Daily for all mainline operations and trips of trains with long stopping distances.	
Pre-conditions	Mainline with OD & TID and communication systems Mainline with equipment and procedures for GoA 2-4 operation Locomotive with external OD & TID system interface installed (compatibility as below) Locomotive equipped for GoA 2-4 operation. Compatibility and communication between trackside OD & TID system(s) and; TMS or alternatively locomotive control).	

Typical use case implementation	Actor (party involved)	Action	System response
	Locomotive operator Infrastructure Manager (trackside OD & TID) Driver/attendant	A1: OD & TID system detects hazard and passes information to (i) TMS, and/or (ii) control system of approaching locomotive. Detection also displayed on	SR1: (i) TMS modifies movement authority/target motion profile for affected trains accordingly and communicates to train control, (ii) and/or train

		locomotive AOD & TID system HMI for information of supervising driver/attendant (where present).	control reacts to hazards. Driver/attendant views information on HMI and uses judgement to determine and implement response to hazard if necessary.
	Locomotive driver Locomotive operator Infrastructure Manager (trackside OD & TID)	A2: OD & TID system detects NO hazard and passes information to (i) TMS, and/or (ii) control system of approaching locomotive. Detection also displayed on locomotive AOD & TID system HMI for information of supervising driver/attendant (where present).	SR3: (i) TMS modifies movement authority/target motion profile and communicates to train control, (ii) and/or train control reacts to hazards. Driver/attendant views information on HMI and continues to monitor for hazards.
Post-conditions	No Hazard detected: Train continues in normal operation Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed and train moves past hazards and continues. In case of GoA2-31, driver might override ATP or hazard detection to continue past hazard before returning to normal operation.		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Normal operation: Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train), train passes hazard safely, or hazard removed, and train moves past hazards and continues. In case of GoA 2-3, driver/attendant input might be required to assess hazard and instruct/override train control and continue past hazard before returning to normal operation. • End of service; Train leaves mainline control (ERTMS/ETCS managed area) or is taken out of service – no longer receiving movement authority/target motion profile from TMS or communicating with OD & TID system. <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications to TMS, OR elements become “active” as requested as train approaches and inactive after train(s) pass. In case of system architecture where elements are switched between active and inactive, switching could be controlled by request/information from TMS or communication with approaching trains. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.		
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible mainline TMS in each area, and locomotive must be compatible with the/all OD & TID systems and TMS along route.		

	• Locomotive and TMS must be equipped with compatible GoA 2-4 systems along route. **Risks:** • Single failure of trackside OD & TID system in critical area could prevent or restrict all operations on mainline if it creates a gap in the detection coverage and there is no redundancy • (GoA 2-3) Driver not observant of hazards or system due to automation and lack of input required • (GoA 4) No driver/attendant supervision to ensure correct operation of system (observe and hazards not detected), operate or supervise train in case of exceptional circumstances, or implement response to hazards (remove obstacles within capability or investigate them) • False positives could cause unnecessary delays or reduce confidence in the system • False negatives could but train at risk • Emergency brake application by TMS/train control could lead to derailment of freight train • Security vulnerability of safety critical wireless communication for OD & TID **Requirements:** • Must be cross compatibility between OD & TID system, the form of train control, and traffic management along whole route
Estimated priority	**Reliability, availability & maintainability: Medium priority** - Current operating system and procedure enables the operation of trains with long stopping distances, adding additional novel components interface, communication and processing requirements might reduce reliability and network/locomotive availability in the short term and increase maintenance requirements. However, implementation of full ATO would allow reduction of requirement for driver/attendant input and presence reducing educing human errors (potentially increasing reliability) and labour costs respectively. **Safety: Medium priority** - Trains with long stopping distance tend to be the highest risk in terms of derailment due to train handling (driver judgement used) and cargo hazard/volatility. Therefore, would benefit the most from assistance in detecting hazards, however, might be the last area where full automation of operation is implemented, and driver/attendant supervision is removed by ATO. **Commercial: Medium/High priority** - Trains with long stopping distances are usually high revenue earners (high volume/weight of cargo), so high priority to ensure they are compatible with network requirements and can continue to operate, and implementation of full ATO would allow reduction of requirement for driver/attendant presence reducing labour costs.
Assumptions and open issues	Assumes compatibility and all systems operative are a requirement for normal operation. Uncertainty regarding system architectures, responsibilities, procedures, i.e. if OD & TID system would communicate directly with train control system, just TMS or some combination, and responsibility and hierarchy for decision making. Also, uncertainty regarding requirements for level of hazard detection and response (would no coverage be treated as stop/slow/caution hazard detected or as no hazard detected).

Conclusion	Overall priority/importance of implementing the UC: • Overall priority is Very High due some form of OD & TID would almost certainly be required as input to automated train control to make risks of ATO acceptable for national/international networks (particularly, the increased risks associated with trains with long stopping distances); therefore, OD & TID would be in continuous use. Estimation of complexity of OD & TID system for the UC: • The design of the OD & TID system and interfaces would be of High-Medium complexity, depending on overall ATO system architecture and division of responsibilities for decision making (in OD & TID, ATC, TMS, etc.) – possibly slightly higher due to more interfaces per train for required detection coverage in this UC. In any case, likely to be an onboard and trackside sensor system using different types of camera and supporting technologies, with interface to other ATO systems (ATC, TMS, etc.) and interface to driver/attendant HMI (either direct or from another system, e.g. TMS). Likelihood of implementation in the future: • Considering the actual requirements of TMS, expected reliance of ATO on OD & TID, and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC, therefore, commercialisation and exploitation is likely in the medium-longer term future (depending on timescale for ATO implementation by IM and RU, in general, and development of standards for ATO under ERTMS/ETCS). Relevance of SMART2 concept to use case: • The SMART2 OD & TID concept is highly relevant to this use case, as the objective of SMART2 is to extend the hazard detection distance in front of a train to up to 2km.

A9. Use Case FS-03: Freight trains operating on shunting yard or similar controlled environment (GoA 0-1)

<table>
<tr><td>Name:</td><td colspan="3">OD & TID use for freight train operating on shunting yard or similar controlled environment (GoA 0-1)</td></tr>
<tr><td>ID:</td><td colspan="3">OTID-UC-FS-03</td></tr>
<tr><td>Actual Scenario</td><td colspan="3">Freight train (or locomotive) operating on shunting yard or similar controlled environment (GoA 0-1)</td></tr>
<tr><td>Scope & Brief Description</td><td colspan="3">An OD & TID system (on driving unit/locomotive and/or trackside) might be required for freight trains operating in a yard without ATO (GoA) 0 or 1) to detect potential obstacles on the track or close to the path of the train, so that the processed information may be used by the driver, ATP, or yard management system to determine the safe extent of movement.
• Freight train in yard/non ETRMS/ETCS area
• Train operating with GoA 0-1 in yard area
• OD & TID system(s) used to supervise the safe movement of trains (check clear of obstructions) in yard areas, might also include:
  o detection and range finding (or detection and exemption under specific conditions) of vehicles intended to make contact with (coupling)
  o detecting route set
  o detecting location reference points (e.g. loading zone)?</td></tr>
<tr><td rowspan="3">Stakeholders involved
(actors)</td><td>Responsible to implement the use case
(primary system actors)</td><td colspan="2">Locomotive operators,
Yard operators</td></tr>
<tr><td>End-users/
Beneficiaries
(primary business actors)</td><td colspan="2">Locomotive operators,
Yard operators
Freight service customers</td></tr>
<tr><td>Other interested parties</td><td colspan="2">Mainline Infrastructure Manager</td></tr>
<tr><td>Frequency of use</td><td colspan="3">Daily – Start, end and some calling points of every freight train/loco journey</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Locomotive with GoA 0-1 system compatible with yard operating system (and OD & TID) or capable of operating independently (without yard management system or ERTMS/ECTS)
Yard area with operating system (and OD & TID) compatible with locomotive, or where independent operation of locomotive is permitted.</td></tr>
<tr><td rowspan="3">Typical use case implementation</td><td>Actor (party involved)</td><td>Action</td><td>System response</td></tr>
<tr><td>OD & TID system operator (yard operator and/or loco operator)</td><td>A1: OD & TID system detects hazard, driver is informed on HMI (e.g. enhanced image of hazard) and responds</td><td>SR1: OD & TID system detects hazard, hazard detection passed to HMI</td></tr>
<tr><td>OD & TID system operator (yard</td><td>A2: (GoA 1 only) OD & TID system detects critical</td><td>SR2: (GoA 1 only) OD & TID system detects hazard, hazard</td></tr>
</table>

	operator and/or loco operator)	hazard (immediate risk to train)	detection passed to HMI and decision system, ATP stops train, ATP activation alerted to driver.
	OD & TID system operator (yard operator and/or loco operator)	A3: OD & TID system detects no hazards relevant to a movement,	SR3: OD & TID system and passes clear signal to Driver HMI, (GoA 1) and decision system, ATP not triggered
Post-conditions	Normal operations: Yard operations continue until end of train/locomotive movement in yard in safe conditions; OD & TID system monitoring/tracking potential hazards Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, or hazard removed/train diverted, and train moves past hazards and continues. Hazard detected, collision unavoidable: The train collided with an inevitable obstacle, but due to speed reduction and warning, the negative consequences were minimised		
Post-use Scenario	<u>Train perspective:</u> • Normal operation: No hazard detected; train continues in normal service. • Hazard detected: Appropriate response implemented (e.g. sound audible warning, slow or stop train, or emergency procedures), train passes hazard safely, hazard removed, and train moves past hazards and continues, or train diverted past hazard. In case of GoA 1, driver might override ATP or hazard detection to continue past hazard before returning to normal operation. Yard operations continue with a possible delay. • End of yard operations; Locomotive and vehicles in required positions in the yard area - no longer communication with OD & TID system or receiving hazard indications/movement authority target motion profile from yard management system. OR Loco/train assembled and awaiting movement authority to enter ERTMS/ETCS region of network <u>OD & TID system perspective:</u> • Normal operational: Either OD & TID system elements active continuously and sending no hazard detected notifications, OR elements become "active" as requested as train(s) move in different area of the yard and inactive after train(s) stop or move to another area. • Hazard detected: Active (either on request or continuous) OD & TID system elements send hazard detected signal until hazard leaves detection/notification area or removed.		
Implementation constraints, risks and requirements	**Constraints:** • OD & TID system must be compatible with the form of train control and traffic management in each yard visited **Risks:** • Single failure of trackside OD & TID system in critical area could prevent or restrict all operations in a yard if it creates a gap in the detection coverage and there is no redundancy • Security vulnerability of safety critical wireless communication for OD & TID		

	Requirements: • Must be cross compatibility between OD & TID system, the form of train control, and traffic management in each yard visited
Estimated priority	**Low priority** because: • The driver still has main train control role and current procedures capable of performing yard operations • ATP/ATO system architecture in yard areas less developed and might not be standardised as soon, therefore interfaces and requirements for OD & TID less clear so motivation for development is lower • Lower benefits of ATP in yard areas (lower speed, lower number of people involved in/affected by incidents
Assumptions and open issues	Method of train control and movement instruction in yards is unclear and affects the interfaces of the OD &TID system with ATP and other systems.
Conclusion	<u>Overall priority/importance of implementing the UC:</u> • Overall priority is Low due to low impact of OD & TID use (current risk with driver and without OD & TID is considered acceptable, and implementation could slightly improve safety), even though high probability of scenario occurrence. If being implemented, OD & TID in yards would be used daily for most starting, calling and end points. <u>Estimation of complexity of OD & TID system for the UC:</u> • The design of the OD & TID system and interfaces would be of Low-Medium complexity, main interface would be a driver HMI, interface with ATP might be more complex depending on overall system architecture and division of responsibilities for decision making (in OD & TID, ATP, Yard Management System, etc.). In any case, likely to be an onboard and trackside sensor system using different types of camera and supporting technologies (trackside only might be sufficient). The complexity may be increased due to need to ensure compatibility (as standardisation may be less/different than on mainline), and/ or due to complex hazards in yards (e.g., staff and equipment close to trains). <u>Likelihood of implementation in the future:</u> • Considering the actual requirements of yard management system, OD & TID, and status of technology developments, it is feasible to resolve the constraints to implementation of OD & TID system for this UC in the near future; however, the, commercialisation and exploitation is uncertain since low priority for GoA 0-1 (driver present and current procedures acceptable), therefore, implementation of OD & TID in yards might not be required until increasing grade of automation. <u>Relevance of SMART2 concept to use case:</u> • The SMART2 OD & TID concept has potential relevance to the OD & TID functions necessary in yard operations, as its sensors and processing could be adapted for this use case. However, development of the SMART2 OD & TID system is focused on mainlines controlled by ERTMS/ETCS, and operations in yard areas are not within the focus of SMART2. A dedicated OD & TID system specifically designed to meet the requirements of yard operations might be a more effective and efficient solution.