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D5.5 Requirements Specification Yard Automation

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1 Executive Summary

This document constitutes the Deliverable D5.5 “Requirements specification Yard Automation” of WP5 in the framework of the Flagship Project FP5- TRANS4M-R as described in the EU-Rail MAWP for Flagship Area 5 “Competitive Digital Rail Freight Services”, while “Automated Train Operation” is the title auf Flagship Area 2.

Regarding Full Digital Freight Train Operation (FDFTO) as it is worked out in EU-Rail JU’s FP5, the subproject Yard has focussed on the service aspects of rail freight, such as wagon processing and therefore looked into the requirements for ASO (Automated Shunting Operation) in context with the DAC (Digital Automated Coupler) as an enabler.

In this document the focus is on the requirements of how to make best use of the DAC and its enabler functions in the yard area. Although called “train functions”, most of them are vital for automated shunting and the use-cases under which this is carried out. Automated Shunting Operation is summarized under the acronym of ASO, in this paper focusing on automated shunting movements. ASO is only applicable in FDFTO shunting mode, uses FDFTO train functions, but does not support train runs itself.

There are two core general use-cases named “hump shunting” and “flat shunting”. While shunting in a hump yard is basically a one-directional workflow, it needs a different operational approach and has a higher goal of automation than shunting in a flat yard, with a never-ending variety of possible scenarios in the yard and its connected last mile.

The aim of this Deliverable is to specify the requirements for the provision of competitive digital rail freight services through yard automation supporting Full Digital Freight Train Operation. Fully Automated Decoupling and Automated Shunting Movements have been identified as the key enablers for automation in yards. Stationary brake test installments and stationary parking brake function as supportive devices until operational target processes can be achieved through full implementation of all related FDFTO-train functions in all European freight wagon fleets. A modular approach was chosen to later allow a stepwise introduction of the described technical enablers, which should finally help to support the DAC migration.

This shall take place accordingly to/with decisions of the System Pillar. In preparation to this, all upcoming amendments regarding technical and/or requirements specifications shall prior be aligned via the FPSE change board as well as being introduced into the POLARION requirements management tool. Furthermore, to align and harmonize interfaces and protocols to ensure integration with other systems such as video-gates (WP29) but also localization devices (Destination 3), Traffic Management System (Destination1) and ATO (Destination 2) to the extent necessary with data streams relevant for shunting, those will also be covered in WP12 in preparation to the Demonstrators WP20&21.

Keywords: Automated Shunting Operation, Yard Management System; Requirements, use-cases, stakeholders

2 Abbreviations & Acronyms

Abbreviation / Acronym	Description
AOCD	Active Operational Concept Developer (Stakeholder strategy)
ASO	Automated Shunting Operations
ATEX	ATmosphères Explosibles Equipment intended for use in explosive atmospheres
ATO	Automatic Train Operation
ATP	Automated Train Protection
BY	Bystanders (Stakeholder strategy)
CA	Consortium Agreement
C=CS	Control-Command and Signalling
CCS	Common Components System
C-DAS	Connected Driver Advisory Systems
CDM	Conceptual Data Model
CEN	European Committee for Standardization
CER	Community of European Railway and Infrastructure Companies
CM	Capacity Management
COM	European Commission
COTS	Commercial Off-the-Shelf
CR	Change Request
DAC	Digital Automatic Coupling
DEMO	Demonstrator
DM	Dissemination Manager
DMI	Driver Machine Interface
EIM	European Rail Infrastructure Managers
EM	Exploitation Manager
EOA	End of Movement Authority
EP	Electro-pneumatic
EP / TP	ER-JU Process / Target Process
EPF	European Passengers' Federation
EU-Rail JU	Europe's Rail Joint Undertaking
ERA	European Railway Agency
ERTMS	European Rail Traffic Management System
ESC	ETCS System Compatibility
ESC	European Securities Committee
ESO	European Standardization Organization
ESR	Electronic Shunting (Path) Request
ETB	Ethernet Train Bus
ETCS	European Train Control System

EUG	ERTMS Users Group
EU-Rail	Europe's Rail
FA	Flagship Area
FDFTO	Full Digital Rail Freight Operations
FFFIS	Form Fit Function Interface Specification
FIS	Functional Interface Specification
FPSE	Flagship Project System Engineers
FRMCS	Future Railway Mobile Communication System
FRS	Functional Requirments Specification
FUSI	Functional Safety Analysis
F-TCN	Freight Train Communication Network
GoA	Grade of Automation
IEC	International Electrotechnical Commission
IM	Infrastructure Manager
IP	Innovation Pillar
IVG	Intelligent Video Gate
JU	(Europe's Rail) Joint Undertaking
MA	Movement Authority
MAWP	Multi-Annual Work Plan
OB	On-board
OBU	On-Board Unit
OC	Operational Concept
OCC	Operation Control Center
PDL	Power Distribution Line
PM	Project Manager
PO	Project Office
PU	Public
QM	Quality and Change Manager
R	Report
RAMS	Reliability, Availability, Maintainability and Safety
RNE	RailNetEurope
RU	Railway Undertaking
S2R	Shift2Rail
SC	Screw Coupler
SP	System Pillar
SPE	Single Pair Ethernet
SRS	System Requirement Specification
TAF TSI	Telematics Applications for Freight Technical Specification for Interoperability
TAF/TAP	Telematics Applications for Freight/Passenger Services

TARO	Towards Automated Rail Operation
TC	Technical Comittee
TC	Technical Coordinator
TCL	Train Communication Channel
TD	Technical Demonstrator
TMS	Traffic Management System
TP / EP	Target Process / ER-JU Process
TRANS4M-R	Transforming Rail Freight
TRL	Technology Readiness Level
TSI	Technical Specifications for Interoperability
TSI WAG	TSI rolling stock - freight wagons
TT	Transversal Topics
TU	Traction Unit
UI	User Interface
UIC	International Union of Railways
UIP	International Union of Wagon Keepers
URS	User Requirement Specification
SP	Sub-Project
TCMS	Train Control and Management System
YAMS	Yard Automation (YAS) and Management System (YMS)

3 Background

The title Full Digital Freight Train Operation (FDFTO) always includes, but hardly explicitly expresses, that the formation of a freight train – an activity which is commonly understood as "wagon processing" or "shunting" – is a vital part of Rail Logistics. The same goes with pickup and delivery of wagons from and to customers, could it be single wagon loads or even up to block trains.

Within TRANS4M-R FP5 Subproject Yard the focus explicitly is on shunting, basically and regularly taking place in yards. This may include last mile stretches and of course customer sidings, but no degraded mode situations, especially not when occurring outside a yard.

The operational experts of CER and EIM have earlier defined the following shunting principles, which are considered similar all over Europe and based on operational experience. (Ref.20150, EEIG&EUG: Operational Concept Description, Enhanced Level 2/3 Shunting) [1] :

- ***SHUNTING*** *is the movement of vehicles from one point of the infrastructure to another when building or splitting trains or groups of vehicles, to and from a "parking" position or a position, where different activities are carried out (Cleaning, repairing, maintenance, catering, fuel...)*
- *Shunting can be done everywhere, means in dedicated areas, on dedicated tracks or main-tracks, on the "open" line or in stations*
- *Vehicles moved in shunting are summarized as SHUNTING-Group, means a vehicle alone or coupled with others. Such coupling can be fixed (Train-set) or used only for one or more movements.*
- *Shunting can be done with a SHUNTING-Locomotive (Here synonym for mainline-locomotive, shunting-locomotive including any rolling-stock foreseen for such ...., yellow-fleet vehicle etc) or by using shunting-hills etc.*
- *The SHUNTING-Locomotive can be operated directly or via remote or radio-control by a SHUNTING-Driver, who could be a fully educated driver according TDD (Train Drivers Directive), a driver with limited competence, an operator of a yellow fleet vehicle, a SHUNTING-Worker with permission etc...*
- *Shunting can be done with a SHUNTING-Locomotive on the front-end, the rear-end or somewhere in between the SHUNTING-group.*
- *The infrastructure (Switches and routes) can be operated manually or by installation, supported by (SHUNTING-) signals or not.*

- *Shunting can be done with signals, hand-signals, oral communication (Direct or via a kind of radio-device) or based on local procedures (Paper order)*
- *Shunting is done (mostly) on sight, means the person who is responsible for the save movement has to see the relevant infrastructure (Tracks, switches) in the relevant area/distance to be able to control the exact movement directly (including radio control) or in-directly (hand-signal, radio etc.).*
- *If the SHUNTING-Driver is not on the front-end in the direction of the movement, he is supported by a SHUNTING-Worker, who has the exact knowledge about the conditions for the movement – means placed on the first vehicle OR at a position of the infrastructure, from where he is able to see the relevant parts. In case of remote-control, this can be ONE person.*

It must be stated, that within FP5 the wording is partly different to the above descriptions and to other previous projects:

Any kind of locomotive is called a traction unit (TU), the driver called TU operator.

A shunting hill called hump.

It also must be considered that major parts of FP5 Full Digital Freight Train Operation (FDFTO) are depending on the so-called "train functions". These train functions will be specified in detail by other Deliverables of WP5 at a later stage.

The building blocks of Automated Shunting Operations (ASO) in a Yard are considered as follows:

FDFTO "Train functions" required for shunting in highly automated hump yard:

- Deactivate Brakes
- Decoupling with DAC5
- Composition & Length Detection
- Automated Brake & Lines Test (trackside hardware)
- Parking Brake

FDFTO "Train functions" required for shunting in automated flat yard and last mile:

- Decoupling DAC5
- Composition & Length Detection
- Parking Brake

Regardless the type of a yard, a Yard Management System (YAMS) consisting of planning (management) and operating (automation) levels with standardized data exchange and protocols is required. Considering that the complexity of yards has a wide range of individual layouts and numbers of tracks (from 2 tracks to high 2digit number track layout) a modular approach for YAMS is considered, also including a mobile version (YAMSmobile)

A traction unit must be equipped with an ASO Onboard unit, including a positioning system, ideally also referring to a digital mapping of the respective yard it is working in.

The TU must be able to communicate with the Yard Management System.

Meanwhile TRANS4M-R WP2 has provided detailed Deliverable 2.1 Preliminary Operational Procedures V1.0 [2] which are currently undergoing another Review process and dissemination among the sector under responsibility of System Pillar task4

This WP2 Deliverable 2.1 Preliminary Operational Procedures V1.0 [2] also forms a vital basis for all considerations of this document. Nevertheless, it will be necessary to go into more detail on some future automated (target) processes when it is about developing an OPErational rule book on automated shunting, aiming towards the target process.

The context of shunting operation, as it is in the scope of this document, is also defined by the following characteristics:

- movement in both directions, including where the TU not only can be positioned at the front of the (pulled) wagon set (shunting composition) but also running in the pushed direction, when other means to observe the track would be needed.
- changing formation, i.e., wagon-data of shunting composition (wagon set) must be updated immediately after every single coupling or uncoupling step. The related "train function" is named "composition detection".
- TU position and its continuous supervision and documentation, which also forms the base of the calculation and documentation of the positioning of every single wagon.

Migration from screw coupler to DAC 5 is the clear goal for Europe`s Rail in FDFTO target state.

DAC 5 has some major different characteristics compared to screw coupler as of today:

DAC type 5 enables remote-controlled or fully automated decoupling and thus has the potential to reduce manual work in marshalling yards with or without hump as well as in flat shunting in general, compared to today.

Along with this comes the need to avoid unintended braking and recoupling of wagons. For the time being (when this paper is submitted) no technical solution is in place for those process steps. In that case bleeding and deactivating of "prevent coupling" must be done manually.

The European Railways are currently in the process of implementing ETCS. The railways have identified an opportunity to achieve improved capacity, on-time performance and make energy efficiency improvements through developing and implementing Automatic Train Operation (ATO) over ETCS.

ATO is the sub-system which performs some or all of the functions of automatic speed regulation, accurate stopping, door opening and closing, performance level regulation, and other functions assigned to a train driver or train attendant.

Current ATO specifications (X2R4-WP05-ATO Operational Principles V 1.10) are focussed on mainline operations where ATO interfaces ETCS and TMS. Remote control is foreseen in degraded mode and for shunting only.

As we will explain later, it is important to have a more sophisticated remote-control system for shunting locomotives operating in a freight yard. In order to be able to manage all possible scenarios in the different freight yards and ensure as much as possible standardization we plan to build the yard automation functions on top of an advanced TU remote control system which constitutes a fundamental element of an Automated Shunting Operation (ASO) architecture.

Such approach will allow the ATO and the ASO to converge into an interoperable solution matching several goals: modularity, smooth migration plan and standardization. Ensuring that the remote-control system embedded in the ATO and the ASO remote control will be using the same standard protocols will allow ATO to operate both in the mainline ("controlled" by the TMS and ETCS) and in the freight yard ("controlled" by the Yard Automation System and/or operators).

ASO performs some or all movement functions for shunting such as distances, changing directions, accurate stopping especially for coupling and decoupling, allowing series of missions based on shunting orders. It shall be able also to drive the TU with an externally defined velocity. All these functions fulfilling the basic use-cases hump operation, flat shunting pickup and delivery, as well as others as they are defined in this paper.

A shunting mission is a sequence of movements and "train functions" (to be) executed. A mission can only be executed when the traction unit and its consists are in shunting mode.

FP5 defines at least two different operation modes; Automated Shunting Operations (ASO) can only be carried out in FDFTO mode Shunting.

FDFT mode Shunting (note: not ETCS Shunting Mode)	Allows electrical uncoupling of DAC coupler heads, electrical activation of function prevent coupling and activation of Automated Parking Brake. When uncoupled, no harmful electrical power on DAC coupler head is present, especially on electrical contacts. When uncoupling, electrical connections of DAC coupler head must be free of harmful electrical power or current prior to mechanical uncoupling. When coupling, harmful electrical power and current is only applied after successful mechanical coupling of both DAC coupler heads including electrical coupler. This mode is required for all consists (wagon and traction unit). All consists of one composition are in the same mode. **FDFT mode Shunting is precondition for ASO-movements (Automated Shunting Operation)**
FDFT mode Train Run	Coupled DAC coupler heads of Train cannot be commanded to uncouple. First and last DAC coupler heads of Train must have FDFT function Prevent Coupling deactivated and this function cannot be activated. Power supply over DAC coupler heads can be enabled by Traction Unit. Automated Parking Brake cannot be activated (current state of discussion). This mode is required for all consists (wagon and traction unit). All consists of one composition are in the same mode. An operational train run is carried out in FDFT mode Train Run. This mode is not to be confused with train integrity monitoring.

In this document the sequence of describing requirements and describing the architecture is not always according to the recommended sequence in the V-model. The presented sequence has been chosen to improve the readability of the document.

4 Objective/Aim

This document has been prepared to provide definitions, requirements and architectural solutions for basic Automated Shunting Operations. Further elaboration of the results from this Deliverable will take place in WP12 with the final objective to provide demonstrators for Automated Shunting Operation in a hump yard (WP21) as well as in flat yards / last mile (WP20), but also seeking synergies with demo train WP15. For that aim in due course also the overall FDFTO architecture being delivered soon by FP5 task 2.3 has to be finally aligned with and the respective use cases to be aligned with System Pillar task 2 (OperationDesign).

The related business goals towards which this paper is contributing, and Subproject Yard is aiming for, are the following:

Business Goal in Hump Yard Automation is:

Full automation, I.e. "No Staff between Track"

Business Goal in Flat Yard Operation is:

Optimum Automation for "Single Staffed Operation" in a yard and along the Last Mile (customer siding)

4.1 Task Description

	Task definition from GA (Task 5.6)	Output of Deliverable
Subtask 5.6.1	Describe the use cases and the operational concept, derive user requirements by determination of the envisaged process flow of automated shunting process in yards. The definition of key stakeholders and their early involvement for review and validation of stakeholders of the operational concept for review and validation	Based on D2.1 Operational Procedures general use-cases for shunting in yards have been described; An extensive stakeholder analysis has been carried out to ensure involvement of the key stakeholders. Further review and validation of the operational processes and concepts still ongoing with System Pillar until FP5 "train functions" are available in detail.

Subtask 5.6.2	Industry will assess the existing technical and operational documentations and work out a detailed technical specification. SMO will lead the automated parking brake (trackside) and automated decoupling on the hump, whereas FT will lead the automated stationary brake test procedure & instruments.	After assessing the existing technical and operational documentations, detailled technical specifications on a trackside automated parking brake, trackside brake test device and on automated decoupling on the hump have been worked out.
Subtask 5.6.3	FTI together with COF will also lead the specification definition of automated movements of a shunting loco without ETCS in a hump yard, flat yard and in last mile operation. ALS will support in specifying the interface required on the locomotives to interact with the automation subsystems	The definition and specification of automated movements of traction units dedicated for shunting, without ETCS in hump yards, flat yards and in last mile operation has been elaborated. The required interfaces between a traction unit (TU) onboard unit (OBU) and the trackside automation subsystem have been specified.
Subtask 5.6.4	The derived specifications and their fit to the user requirements/operational concept will be jointly validated with OEBB-INFRA, PRORAIL and TRV, but also with the identified relevant stakeholders. FTI will lead the derivation of a definition of the system architecture in order to define and harmonize together with SMO and OEBB-INFRA the GoA4 interfaces locomotive on-board system standard interface with DAC, locomotive on-board system standard interface with yard management and automation system (YAMS).	The derivation and definition of a system architecture to harmonize interfaces and protocols between DAC core system, traction unit (TU) onboard unit (OBU) and yard management & automation system (YAMS) has been worked out. It turned out that GoA-levels, originally defined for train runs, cannot directly and fully be applied in freight services such as shunting. A new approach on GoA will be presented to System Pillar once all relevant "train functions" are available.

In order not to cause a delay of this Deliverable, activity 5.6.1 and 5.6.4 in fact could not be fully closed but are dependent on the availability of all "train functions" required for automated shunting operation and also remain active due to validation by the System Pillar. Therefore, the pending points will be handled in WP12, which will finally describe all requirements for the Demonstrators WP20 & 21 including "train functions", protocols and interfaces but will also be documented in POLARION. A new definition of GoA levels for Shunting has already been presented to System Pillar in spite of some open points regarding "train functions".

5 Content of the Deliverable

5.1 Stakeholder analysis

This stakeholder analysis aims at identifying and classifying key rail freight stakeholders in order to early involve them in the development of operational procedures for automated shunting. Throughout the process 70 stakeholders were identified and classified into three groups depending on their foreseen involvement in the development of operational procedures.

This stakeholder analysis was carried out over the time from December 2022 until February 2023 as part of the Expert Group Stakeholder Analysis under the Subproject Yard. The analysis was led by DBC and partners from OEBB-Infra, FH OOE, PRORAIL, TRV, KTH and SBB participated and contributed with their knowledge and expertise.

Hereinafter the process of identifying and clustering is described in the methodology section. Eventually the identified stakeholders are described and finally their assessment into three stakeholder groups that are either actively involved in the development of operational procedures, provide feedback or are bystanders and not involved in the development.

5.1.1 Methodology

The process of the carried-out stakeholder analysis was divided into three major steps and which are described in more detail in the following:

1. Identification of key stakeholders,
2. Classification of the identified stakeholders into four groups depending on their active involvement in the development and how they are updated and informed,
3. Plausibility check and final regrouping the classified stakeholders into three groups depending on their involvement in the development.

5.1.1.1 Identification of key stakeholders

Starting point of the identification of key stakeholders was the stakeholder analysis carried out in the Shift2Rail Project Ben@Rail. This project's main objective was to foster the effectiveness of EU-funded R & I – activities in railway through aligning these activities with the actual needs of the relevant stakeholders [3]. Within their project the Ben@Rail participants have developed a so-called Stakeholder tree presented in D1.1. with As Ben@Rail had a broader approach than FP5-TRANS4M-R their list of stakeholders needed to be adapted. This adaptation was carried out during open discussions and brainstormings in several working sessions within the expert group. The identification of stakeholders was as well aligned with the actors defined in the Work Package 2, namely Deliverable 2.1 Preliminary Operational Procedures V1.0 [2]. The actual description of all identified stakeholders is described in the following section Stakeholder description.

5.1.1.2 Classification of identified key stakeholders

The second step of the stakeholder analysis was the classification of the identified stakeholders and the derivation of involvement strategies. Following an established stakeholder analysis approach [4] the support of all stakeholders and their power/influence on the development of Operational Procedures was determined asking the following questions and rating it on a scale from 1 (low) to 5 (high):

- "How important is the support from this stakeholder for the project?"
- "How influential is this stakeholder to achieve the goals of the project?"

This analysis was carried out in form of a survey within the expert group. Six members of the expert group filled the survey, and their answers were arithmetically averaged. Based on the survey analysis, four strategies were derived, depending on the support [5]and power of the respective stakeholders. These strategies and the conditions for assignment to this strategy and the number of assigned stakeholders are summarized in the following Table 1.

Table 1 Initial Stakeholder strategies and conditions

Strategy	**Conditions**	**Number of assigned stakeholders**
Not informed, not involved (NINI)	Average rating for *support* < 2.5 AND average rating for *power/influence* < 2.5	36
Keep informed, not involved (KINI)	Average rating for *support* ≥ 2.5 AND average rating for *power/influence* < 2.5	5
Keep informed, slightly involved (KISI)	Average rating for *support* < 2.5 AND average rating for *power/influence* ≥ 2.5	6
Fully informed, fully involved (FIFI)	Average rating for *support* ≥ 2.5 AND average rating for *power/influence* ≥ 2.5	23

5.1.1.2.1 Plausibility check and final regrouping of stakeholders

Eventually this assignment of stakeholders to four strategies was checked on plausibility by the expert group in a joint discussion. Based on this discussion it was agreed to reduce the number of strategies, especially because the large number of 23 stakeholders assigned to “Fully informed, fully involved” would limit productive cooperation.

The revision of stakeholder strategies led to a reduction to three strategies. The mapping of the original strategies to the revised strategies is shown in Figure 1 and a detailed description of these three revised strategies is shown in Table 2

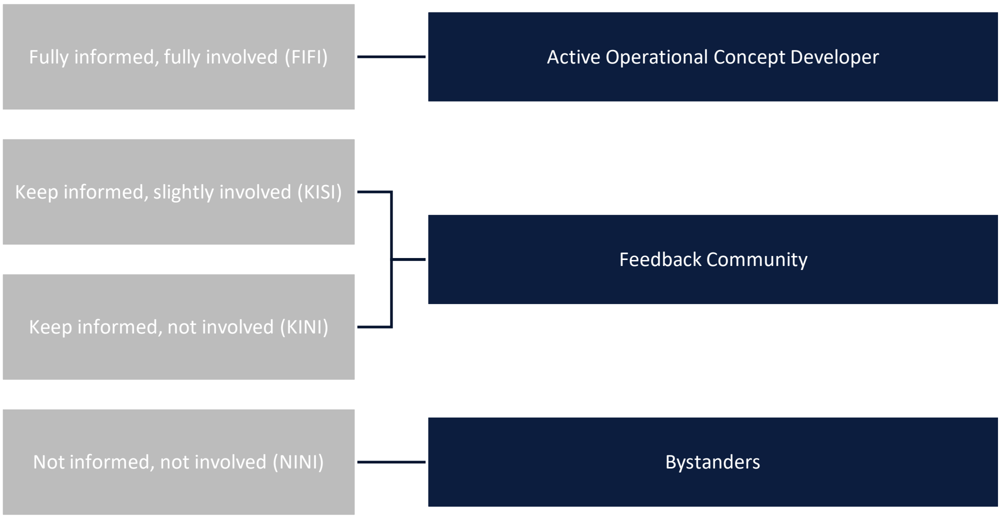


Figure 1: Revision and mapping of stakeholder strategiesTable 2 Revised stakeholder strategies and conditions

Revised strategy	Description of conditions and involvement	Number of Stakeholders assigned to this strategy
Active Operational Concept Developer (AOCD)	Stakeholders that are neither actively involved or informed from our side but will be informed through official FP5 communication/dissemination means. Their position and opinion should be reconsidered from time to time to prevent them being a risk to the project and if so actively reach out to them for feedback	10
Feedback Community (FC)	Stakeholders that are not actively involved but will be informed about the progress and asked for feedback. In general, these stakeholders should give their formal or informal approval to the project.	33
Bystanders (BY)	Stakeholders that are regularly and actively involved in the development of the OC.	27

The revised strategies and the assignment of all stakeholders to these strategies is considered the result of the stakeholder analysis.

5.1.2 Stakeholder description

The above described first step of the stakeholder analysis is the identification of stakeholders and their description. Within this step 70 stakeholders were identified and eventually clustered into 12 categories and 8 sub-categories. Starting point for the identification of stakeholders was the analysis conducted within the Shift2Rail project Ben@Rail, documented in the project's Deliverable 1.1 *Simplified stakeholder tree and weighting matrix of requirements* [5]

The stakeholder categories defined within the framework of the present analysis reflect the target groups defined in the GA of FP5-TRANS4M-R [6] and enhances and diversifies them. Overlaps and correspondences of stakeholder categories and target groups are described in the following description of the categories. Furthermore, there are correspondences of stakeholders identified in this process and actors described in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2]. These correspondences are described below and illustrated in Figure 3. Stakeholder categories, subcategories and target groups are formatted in *italics*, stakeholders are formatted in **bold**.

The stakeholder category *Customer* partly equals the target group *End users and railway community* described in the GA. The overlap are the stakeholders of Shippers and Forwarders which are grouped as the stakeholder **Freight Forwarders**. There are six other stakeholders in this category, divided into two subcategories. The subcategory *Freight-Customers* distinguishes **Freight customers without private sidings** and **Freight customers with private sidings**. The subcategory *Freight Type* distinguishes **Customer with freight type SWL/Bulk**, **Customer with freight type Intermodal**, **Customer with freight type Loose Cargo** and **Customer with freight type block trains**.

The stakeholder category *Train Operator* partly equals the target group *End users and railway community*. The overlap are the stakeholders of Rail Undertakings and their staff. In the framework of this analysis three stakeholders are distinguished: **Freight Train Operating Companies/RUs** in general, the **Maintenance (Train Operator)** of the RUs and the RU's **Locomotive driver (Train Operator)** and. The latter corresponds to the role Operator Traction Unit described in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2].

The stakeholder category *Infrastructure Operator* (IO) partly equals the target group End users and railway community. In the framework of this analysis seven stakeholders are distinguished. **Track (IO)** are responsible for operating the tracks in their network with **Operation Staff** and **Dispatchers**. **Maintenance Staff** takes care of the infrastructure maintenance and **Energy (IO)** provide especially electrical energy for running trains in a network. **Yard Operators** and **Shunting Staff** are responsible for operating shunting yards. The stakeholder Yard Operator comprises the two roles Signaller and Yard Manager described in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2]. The stakeholder Shunting Staff comprises the roles Brake Test Operator, Wagon Inspector and Yard Personnel described in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2]. [4]

The stakeholder category *Provider* partly equals the target group *Supply Industry* described in the GA. In the framework of this analysis this category includes providers for **Construction** and for **Signalling** that build tracks and signalling. Providers for **Communication/Connectivity ICT**, for **IT/Data sharing platforms** and for **Immaterial Services** enable the railway operations in general. Within the subcategory *Wagon Keepers* **Small/private owners (Wagon Keepers)** and **Wagon Keepers: ROSCO** are distinguished. Other stakeholders are those for **Energy (Provider)** that supply with energy especially for non-electric locomotives and **Track (Provider)** that produce and manufacture tracks.

The stakeholder category *Manufacturer* partly equals the target group *Supply Industry* described in the GA. As distinct from the category *Provider* it includes only manufacturers of rolling stock such as **Locomotive Manufacturer**, **Wagon Manufacturer**, **Coupler Manufacturer** and their **Maintenance (Manufacturer)** in general. Manufacturer of **Locomotive Shunting Devices Manufacturer** belong to this category as well.

The stakeholder category *Public/Society* equals the Target Groups *General Public* and *Associations* described in the GA. Within the framework of this analysis seven stakeholders are distinguished, three of which belong to the subcategory *Lobbies/NGOs*: **Rail Forward (Lobby)**, **ATTI (Lobby)** and **GCU (Lobby)**. The other four stakeholders in this category are **European Technology Platforms**, **Unions**, **Residents** and the **Media**.

The stakeholder category *Regulatory Bodies* equals the Target Group *Authorities* described in the GA. This category is divided into two subcategories. Within the subcategory *Regulatory Bodies within railway* the following five stakeholders are distinguished: **Railway Authority**, **Network Agency**, **EU Agency for Railways**, **Safety-/Security Body** and **Standardisation Groups.** The subcategory *Other public regulatory bodies* distinguishes six different stakeholders: **Legislative Authority**, **European Commission**, **Environment Agency**, **Local/national regulations**, **Flight control (focus drones)** and **Radioband/Telecommunications**.

The stakeholder category *Other transport systems* partly equals the target group *End users and railway community*. The stakeholders of this category are divided into three subcategories. **Terminal Operators** and **Truck Operators** belong to the subcategory *Street*. **Port Operators** and **Ship Operators** belong to the subcategory *Sea*. **Airport Operators**, **Airlines/Plane Operators** and **Helicopter Operators** belong to the subcategory *Air*.

The stakeholder category *Investors/Creditors* is not represented by the target groups defined in the GA. It consists of four stakeholders. RUs and IMs can be owned by either **Shareholders** or **States**. **Financial Institutions** ensure investments and **Insurances** insure all kind of companies and organizations in the railway sector.

The stakeholder category *R&I and Academia* equals the Target Group *Scientific Community* described in the GA. Within the framework of this analysis three stakeholders are distinguished: **Universities** and other **Research Institutes** conduct research in the field of railway. **Education/Training** is responsible for the training of staff that works in the railway system, e. g. in RUs and IMs.

The stakeholder category *Emergency Services* is not represented by the target groups defined in the GA. It includes **Customs**, **Firefighters**, **Medics** and **Police**. These stakeholders were added to this stakeholder overview as in case of border-crossing and in case of emergencies they need to intervene.

The stakeholder category *Non-EU countries* is not represented by the target groups defined in the GA. It includes the stakeholders **IM (non-EU)**, **RU (non-EU)** and **Foreign regulatory bodies**. These stakeholders were added to this stakeholder overview as Switzerland and Norway are not part of the European Union and its legislation but are a fundamental part of the European Railway Network.

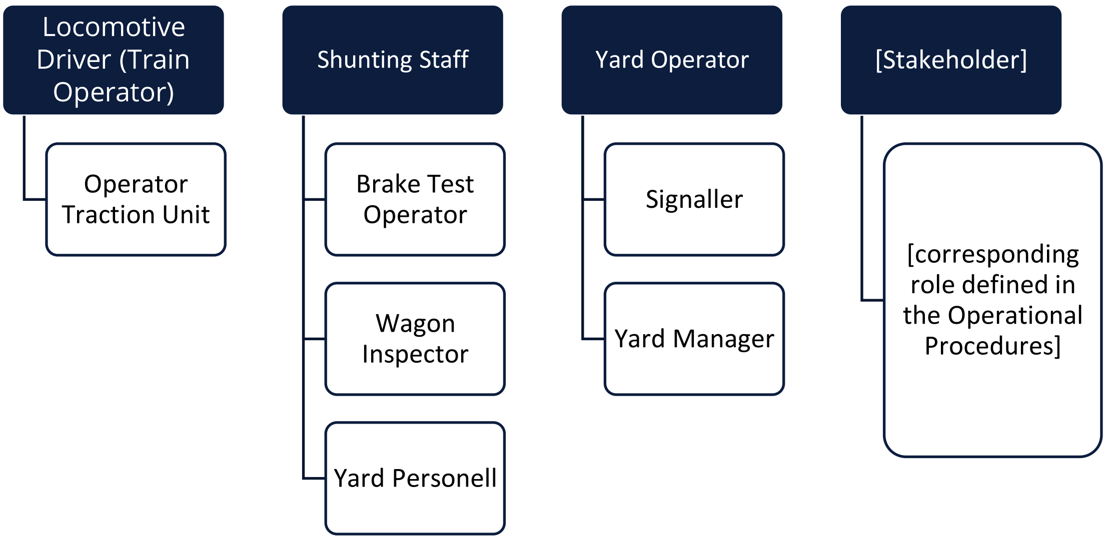


Figure 2: Assignment of actors defined in the Operational Procedures in D2.1 to stakeholders (blue boxes)

The complete overview of all stakeholders described in this section is visualized in the following Figure 3

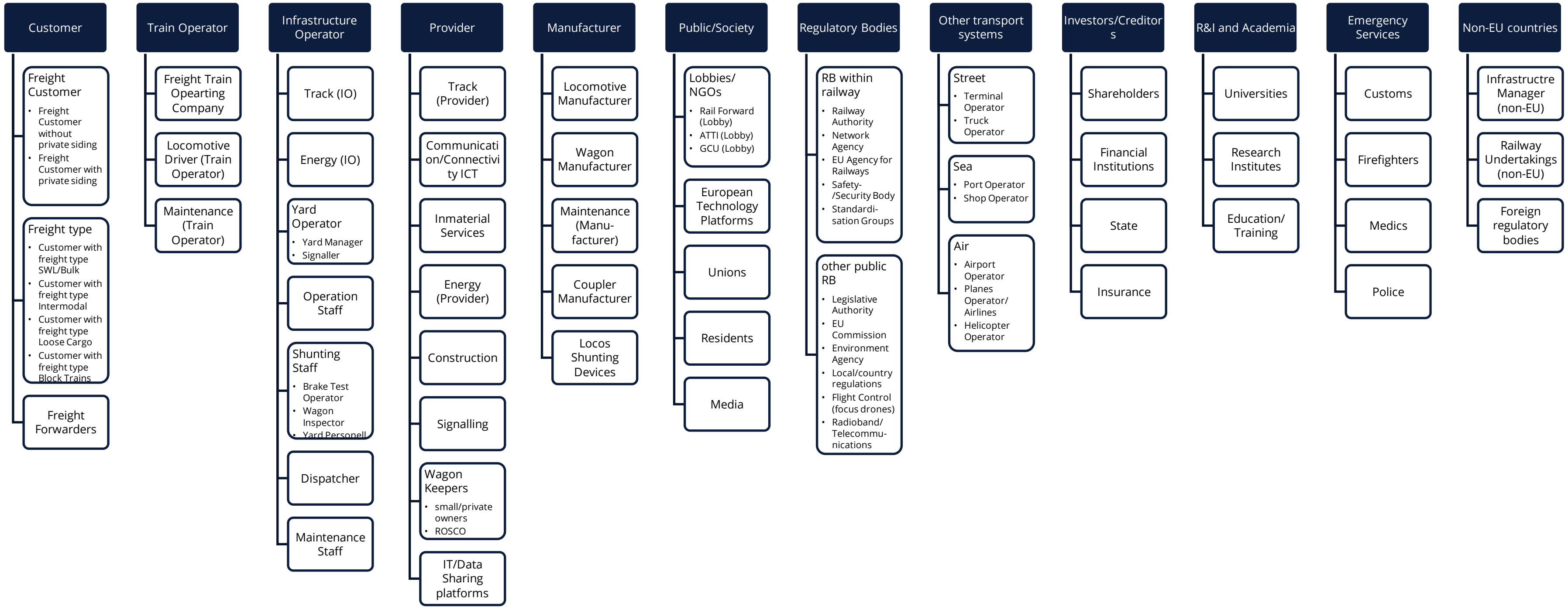


Figure 3 Stakeholder overview with stakeholder categories and subcategories

5.1.3 Stakeholder groups

All stakeholders identified and clustered in the previous sections were classified within the expert group to determine to which extent they should be involved in the development of operational procedures for automated shunting.

For this purpose, all 70 stakeholders were assessed in terms of their importance and influence within the framework of a survey in the Expert Group. Based on the survey, they were initially assigned to four strategies for their involvement. In a plausibility check, the number of strategies was reduced to three and the assignment of stakeholders to these strategies was revised.

The assignment of stakeholders to the three categories is described below in the following Table 3

Table 3 Overview of the assignment of all stakeholders to a strategy

Stakeholder strategy	**Assigned Stakeholder**	
	Category	**Stakeholder**
Active Operational Concept Developer	Train Operator	Loco Driver (Train Operator)
	Regulatory Bodies	EU Agency for Railways
	Train Operator	Freight Train Operating Company/RU
	Infrastructure Operator	Yard Operator
	Provider	Communication/Connectivity ICT
	Provider	Signalling
	Manufacturer	Locomotive Manufacturer
	Manufacturer	Locos Shunting Devices
	Regulatory Bodies	Safety-/Security Body
	Regulatory Bodies	Standardisation Groups
Feedback-Community	Train Operator	Maintenance (Train Operator)
	Public/Society	GCU (Lobby)
	Regulatory Bodies	Legislative Authority
	Regulatory Bodies	Local/country regulations
	Other transport systems	Terminal Operator
	Other transport systems	Port Operator
	Emergency Services	Firefighters
	Non-EU countries	Infrastructure Manager (non-EU)
	Non-EU countries	Foreign regulatory bodies
	Infrastructure Operator	Maintenance Staff
	Provider	small/private owners (Wagon keeepers)
	Public/Society	Rail Forward (Lobby)
	Non-EU countries	Railway Undertakings (non-EU)
	Customer	Customer with freight type Intermodal

	Customer	Freight Forwarders
	Manufacturer	Maintenance (Manufacturer)
	Regulatory Bodies	Flight Control (focus drones)
	Regulatory Bodies	Radioband/Telecommunications
	Customer	Freight customer with private siding (bigger company; e.g. VABU in Austria)
	Customer	Customer with freight type SWL/Bulk
	Infrastructure Operator	Track (IO)
	Infrastructure Operator	Operation Staff
	Infrastructure Operator	Shunting Staff
	Infrastructure Operator	Dispatcher
	Provider	Wagon Keepers: ROSCO
	Provider	IT/Data sharing platforms
	Manufacturer	Wagon Manufacturer
	Manufacturer	Coupler Manufacturer
	Public/Society	Unions
	Regulatory Bodies	Railway Authority
	Regulatory Bodies	Network Agency
	Regulatory Bodies	EU Commission
	Investors/Creditors	State
Bystanders	Customer	Freight customer without private siding (SME)
	Customer	Customer with freight type Loose Cargo
	Customer	Customer with freight type Block Trains
	Infrastructure Operator	Energy (IO)
	Provider	Track (Provider)
	Provider	Immaterial Services
	Provider	Energy (Provider)
	Provider	Construction
	Public/Society	ATTI (Lobby)
	Public/Society	Residents
	Public/Society	Media
	Regulatory Bodies	Environment Agency
	Other transport systems	Trucks Operator
	Other transport systems	Ship Operator
	Other transport systems	Airport Operator
	Other transport systems	Planes Operator / Airlines
	Other transport systems	Helicopter Operator
	Investors/Creditors	Shareholders
	Investors/Creditors	Financial Institutions

Investors/Creditors	Insurance
R&I and Academia	Universities
R&I and Academia	Research Institutes
R&I and Academia	Education/Training
Emergency Services	Customs
Emergency Services	Medics
Emergency Services	Police
Public/Society	European Technology Platforms

Actor / Swimlane	Description
Brake Test Operator (BO)	On site personnel performing the brake test.
Consist (A) (B)	A consist is the smallest railway rolling stock entity for operation (e.g. wagon, traction unit,…), containing one CCU representing one node on DAC network. It can be a traction unit, single wagon as a fixed set of single vehicles (segments) which are not disconnected while operation. A consist own a unique vehicle identification number.
FDFT Backend (BE)	Collection of new FDFT functions on land side. Receives, supplies, and stores Consist Data (e.g. Wagon Target Track Data, Traction Unit Status Data, Wagon Set Data and Additional Wagon Data). FDFT Backend provides and receives data to and from other systems (FDFT Yard, Traction Unit, etc.) FDFT Backend initiates different functions, e.g., coupling and uncoupling processes, in Target State.
FDFT Yard (FY)	FDFT Yard is infrastructure based and controls all infrastructure elements in its area. FDFT Yard provides current state of infrastructure to FDFT Backend if available. The interfaces between FDFT Backend and FDFT Yard will be defined in a later step.
Mobile HMI (HM)	(Locally) (remote) device for personnel to interact with FDFT Systems. Connection to FDFT Systems can be wireless and physical, even to FDFT Wagon Base System. For example, personnel can connect the Mobile HMI to a wagon in a wagon set and retrieve Wagon Status Data and Wagon Set Data of the entire Wagon Set.
Operator TU (O)	Personnel (remotely) controlling Traction Unit(s).
Personnel (P)	Only for subprocesses. Refers to the originating swim lane actor in the main process. E.g. if subprocess activity was on the *Yard Manager* swim lane, Personnel refers to *Yard Manager* in the subprocess context.
Signaller (S)	Performer in charge of the route setting of trains/shunting

	movements and of issuing instructions to Operator of Traction Unit (see TSI OPE).
Stationary Device (SD)	Infrastructure-sided device that provides air for (automated) brake test and measurement data (e.g. air pressure). For target processes: Power and data are also supplied and connected. Over this device, a connection between Wagon(s) to FDFT Backend or Legacy Systems is possible.
Traction Unit (TU)	• A Traction Unit with DAC coupler heads that supplies traction power and moves itself and coupled vehicles. This also includes multiple traction units moving together. • The DAC coupler heads can also be hybrid couplers. • A Traction Unit can also have Distributed Power System functionalities. • ATO and ASO systems can be applied. • A Traction Unit can be equipped with FDFT functionalities, e.g. allows retrieving Wagon Status Data or Wagon Set Data and can initiate FDFT Wagon Base System's functions, like secure against rolling away, bleeding, etc. • An unpowered Traction Unit is considered and behaves like a wagon with FDFT Wagon Base System. • Traction Units can be main line locomotives, shunting locomotives, shunting devices, two-way vehicles, etc. • The traction unit (TU) supplies the electrical energy for all the wagons in a train, if technical available. • User Interface is available
Wagon Inspector (WI)	On site personnel performing technical inspection of wagon(s).
Wagon/Wagon Set (WWS)	Wagon: Single physical freight Wagon equipped with DAC coupler head at each end. Wagon(s) permanently coupled (just one UIC Number) together should behave like a single wagon and cannot be uncoupled. Wagon Set: Wagon(s) coupled together by DAC coupler heads.
Yard Legacy System (YL)	Today's technical systems used in yard operations.
Yard Manager (YM)	Personnel responsible for operation of shunting yards.
Yard Personnel (YP)	On site personnel needed for manual shunting operations, e.g. for uncoupling / coupling rolling stock, for securing rolling stock and any other activities that require human intervention in shunting operation.

5.2 Use cases (UC) and Operational concept

5.2.1 Use Cases

How Yard Use Cases (UC) have been derived:

TRANS4M-R project has in WP2 delivered a series of operational procedures for Full Digital Freight Train Operation (FDFTO), containing lists of actions or event steps typically defining the interactions between a role, also known as stakeholder or actor (e.g., operator, signaller, etc.), and a system (> FDFT system) to achieve a goal. The actor can be a human or an external system (e.g., FDFT back end, YAMS, etc.).

With the target processes (TP) defined in D2.1, a good basis for an overall use case selection for this document is formed. Nevertheless, the scope of this deliverable lies in the general processes, whereas further (sub-)processes form incremental parts of them. Others are on purpose not in scope of this paper, as they will be detailed later in other Deliverables of FP5:

TP01 – Shunting Preparation - in scope

TP02 – Wagon Processing - in scope

TP03 – Train Preparation - not in scope

TP04 – Train Run - not in scope

TP05 – Hump Shunting - in scope

TP06 – Fly Shunting - not in scope, as not compatible with ASO

TP07 – Flat Shunting Drop Off – in scope (with customer interface: last mile delivery)

TP08 – Flat Shunting Pick Up - in scope (with customer interface: last mile pickup)

TP09 – Automated Brake Test -in scope as trackside automation, but not as train function

TP10 – Confirm Wagon Set - in scope as incremental part of other use-cases

TP11 – Technical Wagon Inspection - not in scope

TP20 – Uncouple - in scope, also incremental part of other use-cases

TP21 – Couple - in scope as incremental part of other use-cases

TP22 - Secure Wagon (Set) against Rolling Away - in scope as incremental part of other use-cases

TP23 – Remove, Release Braking Means - in scope as incremental part of other use-cases

TP25 – Apply Parking Brake - in scope, as incremental part of other use-cases

TP26 – Release Parking Brake - in scope , as incremental part of other use-cases

TP30 – Switch to FDFT mode Shunting – in scope as incremental part of other use-cases

TP31 – Switch to FDFT mode Train Run - not in scope

TP32 – Composition Detection – in scope, as incremental part of other use-cases

TP41 – Addition, Removal of Wagon (Set) - decoupling, incremental

TP42 – Addition, Removal of Traction Unit – decoupling, incremental

TP43 – Change of Operator – not in scope

Together with the above mentioned "target operational processes" (TP) intermediate processes (EP) have been worked out by WP2. In a system engineering approach use cases were defined, considering that within software engineering use cases are described on an even more detailed level:

EP 01 Shunting Preparation

UC1 - Confirm Wagon set

UC1.1 – initiate collection, collect and provide consist status data from Traction Unit cab

UC1.2 – initiate collection, collect and provide consist status data near the consists

UC2 - Secure Wagon (Set) Against Rolling Away (EP22)

UC2.1 - apply parking brake (EP25)

UC2.1.1 - initiate apply parking brake(s) from Traction Unit cab

UC2.1.2 - initiate apply parking brake(s) near the consists

UC2.1.3 - initiate actuation of parking brake(s)

UC2.1.4 - actuate parking brake(s)

UC2.1.5 - provide brake(s) status

UC2.1.6 - check if parking brake(s) was applied from Traction Unit

UC2.1.7 - check if parking brake(s) was applied near the consists

UC2.2 - apply service brake

UC3 - Switch wagon(s) of set to FDFT mode Shunting (EP30)

UC3 (BE) - Switch wagon(s) of set to FDFT mode Shunting (EP30) with Backend

UC3.1 - initiate switch to FDFT mode Shunting from Traction Unit cabin

UC3.2 - initiate switch to FDFT mode from near the consists

UC3.3 - deactivate 400V power supply

UC3.4 - activate FDFT mode Shunting

UC3.5 - switch to FDFT mode Shunting

UC3.5 (BE) - switch to FDFT mode Shunting

UC3.6 - Stop monitor train run and provide integrity status to CCS

UC3.7 - Provide status report FDFT mode Shunting

UC3.7 (BE) - Provide status report FDFT mode Shunting with Backend

UC3.8 - Check FDFT mode shunting from Traction Unit cabin

UC3.8 (BE) - Check FDFT mode shunting with Backend

UC3.9 - Check FDFT mode shunting from near the consists

UC4 - Ensure Rolling capability from Traction Unit cab

UC4 (BE) - Ensure Rolling capability with Backend

UC5 - Ensure Rolling capability near the consists

UC6 - Uncouple (EP20)

UC7 - Initiate movement of Traction Unit

UC7 (BE) - Initiate movement of traction unit with Backend

EP02 - Wagon Processing

UC8 - Couple (EP21)

UC8.1 - do not -fill brake pipe with air

UC8.2 – Check if FDFT function prevent coupling is deactivated from traction unit cabin

UC8.2 (BE) – Check if FDFT function prevent coupling is deactivated with Backend

UC8.3 – Check if FDFT function prevent coupling is from near the consists

UC8.4 – Initiate deactivation of 400V power supply

UC8.4 (BE) – Initiate deactivation of 400V power supply with Backend

UC8.5 - Deactivate 400V power supply

UC8.5 (BE) - Deactivate 400V power supply with FDFT Backend

UC8.6 - DAC coupler head couple

UC9 – Remove, Release Braking Means (EP23)

UC9.1 - release parking brake (EP26)

UC9.1.1 – initiate Release parking brake(s) from Traction Unit cab

UC9.1.1 (BE) – initiate Release parking brake(s) from the traction unit cab with FDFT Backend

UC9.1.2 – initiate Release parking brake(s) from near the consist

UC9.1.3 – initiate actuation of parking brake(s)

UC9.1.4 - actuate parking brake(s) to be released

UC9.1.5 - provides parking brake(s) status

UC9.1.6 - check parking brake(s) from traction unit

UC9.1.7 - check parking brake(s) from near the consist

UC9.2 - releases service brake

UC9.3 - check planned braking means from traction unit

UC9.4 - check planned braking means from near the consists

UC10 - ensure enough brake power is available from the traction unit

UC11 - ensure enough brake power is available near the consist

UC12 - shunting composition is ready for shunting checked from traction unit

UC13 - shunting composition is ready for shunting checked near the consist

UC14 - Hump Shunting (EP05)

UC15 - Fly Shunting (EP06)

UC15.1 - initiate acceleration

UC15.2 - accelerate shunting composition

UC15.3 - initiate deceleration

UC15.4 - Traction Unit decelerates shunting composition

UC15.5 - sort wagon into track

UC16 - Flat Shunting Drop Off (EP07)

UC17 - Flat Shunting Pick Up (EP08)

EP03 - Train Preparation

EP04 - Train Run

UC31 - initiate start train run

UC32 - Start train run

UC33 - Test rolling behaviour

UC34 - Test braking behaviour

UC35 - Train stops in target track

UC36 - Addition, Removal of Wagon (set) (EP41)

UC36.1 - brake and wagon (set) calculation

UC36.2 - check technical wagon inspection of added wagon(s) and brake power of consist composition

UC37 - Addition, Removal of Traction Unit (EP42)

UC37.1 - configure DPS/multiple traction units

UC38 – Change of Operator (EP43)

UC38.1 - leave information for succeeding operator

UC38.2 – Operator of TU signs off

UC38.3 – Operator of TU signs on

UC38.4 – initiates composition detection

UC39 – stop train run

EP05 - Hump Shunting (UC14)

EP06 - Fly Shunting (UC15)

EP07 - Flat Shunting Drop off (UC16)

EP08 - Flat Shunting Pick Up (UC17)

EP09 - Automated Brake Test

EP10 - Confirm Wagon Set (UC1)

EP11 - Technical Wagon Inspection

EP20 – Uncouple (UC6)

EP21 – Couple (UC8)

EP22 - Secure Wagon (Set) Against Rolling Away (UC2)

EP23 – Remove, Release Braking Means

EP25 - Apply Parking Brake

EP26 - Release parking brake

EP30 - Switch wagon(s) of set to FDFT mode shunting (UC3)

Earlier the EEIG ERTMS Users Group has created a document that contains a list of use cases with impacted stakeholders and the respective lead contributor for each use case. Only CCS related used cases were then described in detail and can be found in Appendix 8.1

Those use cases are most relevant for RUs from CCS point of view; However, it was stated, that there may be additional use cases to be implemented in an intelligent freight train based on DAC.

Further, in X2Rail4 ATO scenarios have been defined by EUG, which also lead to use cases, some of them actually coinciding with those mentioned above, thus also becoming part of future Automated Shunting Operation (ASO) within FDFT shunting mode. This list of regular scenarios together with a short comment on the relevance for FDTO Automated Shunting Operation from Yard perspective can be found in Appendix 8.2

A documentation of use cases for Remote Driving will be delivered by FP2 Rail from Digital automated up to autonomous train operation in D5.4.

The most common scenarios to be considered in the use-cases relevant for shunting in yards are shown in the following diagrams.

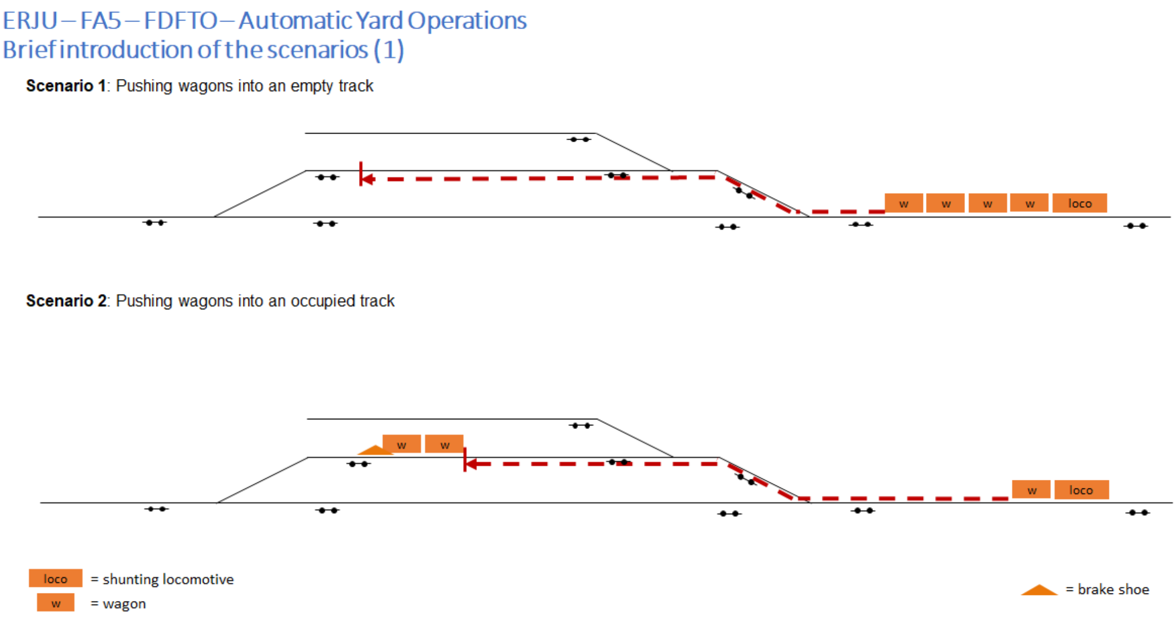


Figure 4: Brief introduction of the scenarios (1)

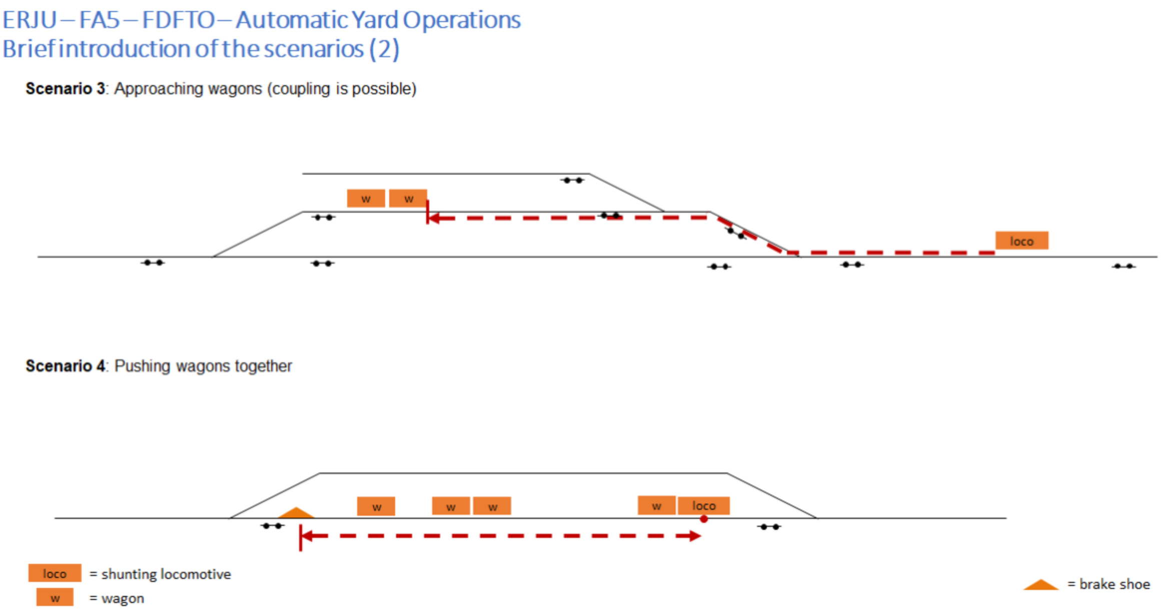


Figure 5: Brief introduction of the scenarios (2)

ERJU – FA5 – FDFTO – Automatic Yard Operations
Brief introduction of the scenarios (3)

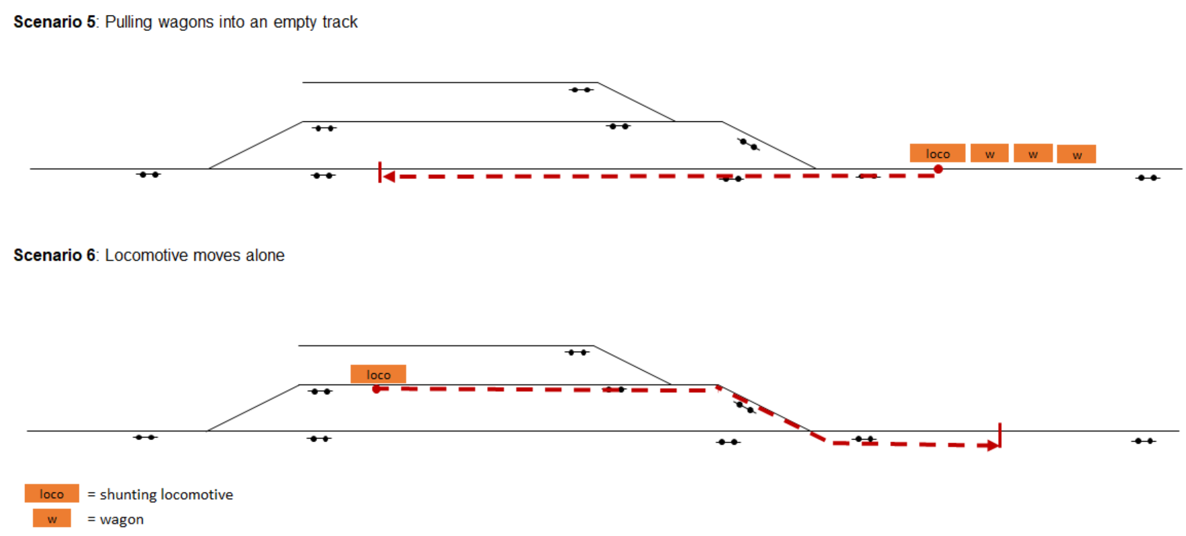


Figure 6: Brief introduction of the scenarios (3)

Finally, the following diagram depicts an overview on relevant use cases for shunting in yards. The green marked use cases in a kind of hierarchical order will be considered in more detail in the following chapters.

As this document focusses on yard automation, the so-called FDFTO train functions itself are of course considered, but not described in detail in this document.

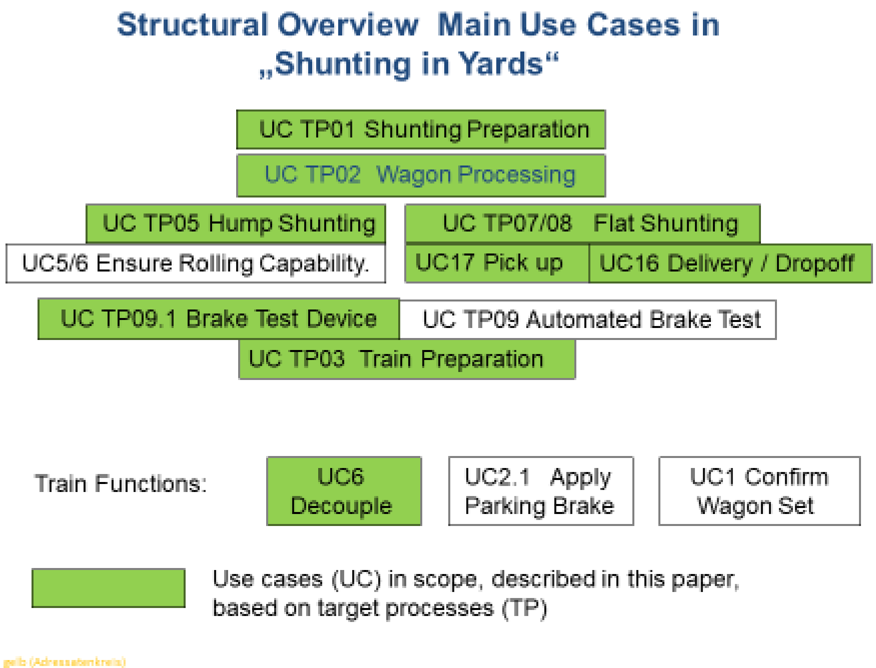


Figure 7: Structural Overview Main Uses Cases “Shunting in Yards”

Table 4: UC TP01 Shunting Preparation ASO

Use case title & ID	Shunting Preparation UC TP01
Use case group	-
Main actor	Yard Management System, Operator Traction Unit
Other actors	Yard Manager, Signaller, Traction Unit, Wagon/Wagon Set
Pre-conditions	Train arrived in target track; composition in shunting mode; composition data in YAMS; wagon destinations in YAMS TU scheduled for shunting coupled to wagon set
Primary flow	1. TU connects to YAMS and confirms composition data 2. YAMS provides split list to DAC (core system) 3. Operator requests shunting path(s) 4. Signaller provides shunting path(s) to TU OBU
Alternate flow / exception flow	Hump yard: UC5/6: Ensure rolling capability (wagon brakes disabled) Last mile: brake calculation may be required
Post-conditions (success and failure)	Wagon Set is ready for shunting. All consists of the shunting composition are in FDFT mode shunting. Shunting path(s) ready for movement mission.
Remark	

Table 5: UC TP02 - Wagon Processing ASO

Use case title & ID	TP02 - Wagon Processing ASO
Use case group	-
Main actor	YAMS, Operator Traction Unit
Other actors	Traction Unit, Yard Manager, Wagon/Wagon Set
Pre-conditions	Shunting preparation is finalised; Wagon destination data and split list available in YAMS (=shunting order); Shunting path available to TU OBU. YAMS can communicate with FDFT Wagon Base System (CCU) to every single wagon in composition via TU OBU, herewith YAMS can detect the order and orientation of each wagon in composition
Primary flow	1. YAMS Initiates movement of TU via OBU towards defined position = mission 2. Movement of Traction Unit towards defined position (defined distance(s) & change(s) of direction) 3. Coupling or Decoupling of consist(s) 4. Composition detection data update to YAMS after every single step 3 activity (coupling & decoupling) 5. Repetition of 1.-4. until shunting order has been fulfilled
Alternate flow / exception flow	-
Post-conditions (success and failure)	Wagon(s) are parked in planned position; could be new train composition ready for train preparation
Remark	Planned sequences of mixed steps 2-3 carried out repeatedly (=missions)

Table 6: UC6 - Uncouple ASO

Use case title & ID	UC6 - Uncouple (TP20)
Use case group	TP02
Main actor	YAMS; Operator Traction Unit
Other actors	Yard Personnel, Traction Unit, Consist A, Consist B, Wagon/Wagon Set
Pre-conditions	Shunting composition with DAC5 is in FDFT mode Shunting. Shunting preparation finished (TP01)
Primary flow	1. YAMS via TU OBU initiates uncoupling at split point / uncoupling point of shunting composition and deactivation of 400V power supply from Traction Unit (UC6.1). 2. TU starts separation movement (by direction change) 3. New shunting composition confirms successful uncoupling to YAMS via TU
Alternate flow / exception flow	
Post-conditions (success and failure)	Consists are uncoupled at planned split point / uncoupling point. Shunting order or at least mission has been fulfilled; all related FDFTO status and position data available in YAMS
Remark	Ad 2.: separation movement according to mission for next scheduled stopping point; if no mission available: minimum separation 25cm; more if required with longer composition due to longitudinal extension (t.b.d.)

Table 7: UC14 - Hump Shunting ASO

Use case title & ID	UC14 - Hump Shunting ASO
Use case group	TP02, TP05
Main actor	YAMS; Operator Traction Unit,
Other actors	Yard Personnel, Wagon / Wagon Set, Traction Unit
Pre-conditions	Shunting preparation finalised
Primary flow	1. TU OBU starts pushing wagon set 2. YAMS via Traction Unit uncouples according to split list at calculated uncoupling point 3. YAMS brakes the wagon(set)s) into and in classification track 4. Wagons couple automatically in target track 5. TU stops after decoupling last consist 6. TU changes direction and returns to parking place or to arrival track for next mission
Alternate flow / exception flow	Yard Personnel sufficiently secures Wagon (Set) against rolling away (UC2) if no parking brake available
Post-conditions (success and failure)	Wagon (set) is secured in the right classification track.
Remark	

Table 8: UC16 - Flat Shunting / Last mile Delivery ASO

Use case title & ID	UC16 - Flat Shunting / Last Mile Delivery ASO (TP07)
Use case group	TP02, TP07
Main actor	YAMS, Operator Traction Unit, Traction Unit
Other actors	Yard Personnel
Pre-conditions	Shunting preparation finalised; planned mission; shunting path requested and permitted
Primary flow	1. YAMS via TU OBU moves TU to defined target position 2. Wagon(s) behind split point getting braked 3. Wagon(s) at split point getting decoupled 4. TU (together with non decoupled wagons) seperates from delivered wagons. 4. Customer information about delivery
Alternate flow / exception flow	-
Post-conditions (success and failure)	Wagon/Wagon Set parking in siding or customer premises and is secured against rolling away.
Remark	

Table 9: UC 17 - Flat Shunting Pick Up ASO

Use case title & ID	UC 17 - Flat Shunting Pick Up ASO
Use case group	
Main actor	YAMS, Operator Traction Unit, Traction Unit,
Other actors	Yard Personnel
Pre-conditions	Shunting preparation finalised (if required) (Simplified) Technical Wagon check carried out (if required)
Primary flow	1. YAMS sends mission to TU to move along defined distance 2. Traction Unit (shunting composition) approaches wagon (set) 3. Shunting composition couples to wagons and activates them 4. Simplified Technical Wagon Check carried out (if required) 5. Automated brake test carried out (if required) 6. Data update from detected composition delivered to YAMS 7. Next mission planned and path requested by TU Operator 8. YAMS sends next mission to TU to move along defined distance
Alternate flow / exception flow	
Post-conditions (success and failure)	Activated Wagon/Wagon Set joined TU shunting composition.
Remark	

Table 10: UC 09.1 – Brake Test Device ASO

Use case title & ID	UC 09 – Brake Test Device ASO
Use case group	TP09
Main actor	Yard Management System, Yard Manager
Other actors	Brake Test Operator; Wagon Inspector Yard Manager
Pre-conditions	Wagon set is secured against rolling away in target tracks and the wagon set processing is completed.
Primary flow	1. YAMS / Yard Manager initiates Device for Automated Brake Test (ABT) 2. Stationary ABT Device connects to first arriving wagon 3. Detection of composition 4. Perform automated brake test (UC20) 5. Calculate braking power 6. ABT device sends preparation data to YAMS 7. ABT disconnects from wagon set
Alternate flow / exception flow	Without stationary ABT device: all required steps carried out by TU (operator)
Post-conditions (success and failure)	Wagon set is ready for attaching TU to do final brake test, exchange train run data with YAMS including "train ready" status to signaller.
Remark	The functionality of the train function "Automated Brake Test" (ABT) will be similar to passenger trains and is therefore not described further in this doc.

Table 11: UC TP03 - Train Preparation

Use case title & ID	UC TP03 – Train Preparation
Use case group	TP03
Main actor	Wagon Inspector, Yard Manager, Yard Personnel, Operator Traction Unit, Yard Management System, Traction Unit, Brake Test Operator
Other actors	Wagon Inspector
Pre-conditions	Wagon set is secured against rolling away in target tracks and the wagon set processing is completed. TU coupled to wagon set (not in Sub-UC TP 09.1)
Primary flow	1. Operator Traction UnitYard Personnel or Yard Manager initiates train preparation (UC18) 2. Stationary Automated Brake Test Device ABT Device connects to wagon (set) (Sub-UC TP09.1 only) 3. Composition detection confirms wagon set. 4. Brake test carried out 5. Wagon inspection carried out 6. Braking power calculated. 7. Stationary ABT Device disconnected (UC TP09.1) 8. Movement and coupling of Traction Unit to wagon set (Sub-UC TP09.1 only) 9. Operator Traction Unit switches to FDFT mode Train Run. 10. Operator Traction Unit performs final brake test 11. Operator Traction Unit compiles, checks, sends all necessary train data to YAMS and confirms train ready for departure 12. YAMS checks train data; signaller sends data required for train run and gives permission for departure.
Alternate flow / exception flow	If no stationary device for ABT is available (Sub-UC09.1) all steps carried out by traction unit (operator)
Post-conditions (success and failure)	Train is ready and allowed for departure.
Remark	

5.2.1.1 Yard Management System (YMS)

The Yard Management System (YMS) is the operational headquarter within the yard. In this system, all important information converges and is used as a basis for the implementation of operational tasks.

These can be manual operating actions by an operator on the basis of the planned procedures or, in later expansion or development phases, decisions made automatically by algorithms or Artificial Intelligence (AI) based systems.

It should also be possible to use the YMS with mobile devices (YMSmobile) as part of certain activities. This could, for example, be used to order and report activities to be carried out in the field. In addition, the visualization of the current conditions in the yard on mobile devices, for example, could be an important aid for employees.

Basically, the expansion stage and the scope of the YMS depends on the characteristics of the respective yard. This applies both to the basic architecture (hump or flat shunting) and to the size and equipment of the yard with other infrastructure-related facilities (e. g. automatic brake test systems etc.).

In contrast to the Yard Automation System (YAS), the Yard Management System (YMS) is not a security-relevant system.

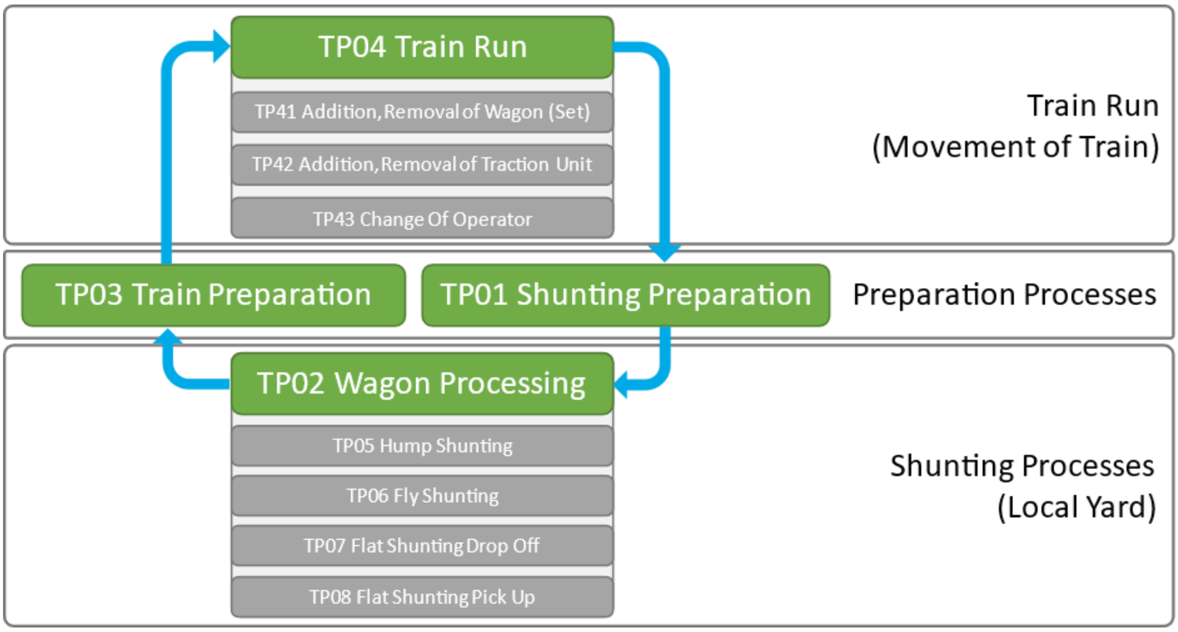


Figure 8: Overview main processes

Based on the four main processes defined in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2] the YMS is mainly involved in the processes where the train mode is switching from "Train Run" to "Shunting Mode" or vice versa:

- TP01 Shunting preparation
- TP02 Wagon Processing and
- TP03 Train preparation

The YMS receives information regarding the planned activities in the yard from a yard planning system (yard planner). These are pre-planned activities based on the trains that will arrive at the yard in a specific time frame and the resulting trains that have to leave the yard in a new consist at a planned time.

Depending on the current state of equipment of the yard, planning can be carried out manually or supported by automatic planning system(s).

The YMS must be able to provide and implement the necessary functions for the yard specific, necessary activities according to the defined operational procedures (Deliverable 2.1 Preliminary Operational Procedures V1.0 [2]) and use cases.

5.2.2 Hump Shunting Operation

The aim of this section is to present how the DAC5, particularly its remote decoupling functionality, can be utilized in hump yards once a full migration to the DAC5 is completed.

The coupling/decoupling characteristics of the DAC relevant to this section are as follows:

- Decoupling should be performed when the coupler heads are experiencing either neutral or compressive forces.
- After the decoupling an immediate, automatic recoupling is possible, unless the "prevent recoupling" function is activated.
  - The couplers must be set to the "ready to couple" mode before the wagons reach the classification track if the "prevent recoupling" function has been activated.
- Preferably, both the decoupling and the activation of the "prevent recoupling" function have to be performed on both coupler heads in order to reduce the abrasive wear of the couplers.

The following chapters describe different concepts utilizing or working around these characteristics.

5.2.2.1 General Concept for Decoupling Wagons in Hump Yards

The concept for the activities WP12/WP21 and Task 5.6 conforms with the operational concept of WP2, but only focusses on certain parts of it, each involving the decoupling process. These parts form certain restrictions for the specific concepts for decoupling in hump yards. These restrictions are as follows:

- The decoupling of every wagon or wagon group is done on the hump.
- For each wagon or wagon group the location, where the compressive forces of the coupler heads in question turn into tensile forces, has to be estimated or calculated.

- The decoupling has to be triggered before (but not too long before because of the prevent recoupling time) this location and not necessarily when the coupler heads are at this location.
- As is the current understanding, when remote decoupling is executed, the coupler heads go into the "prevent recoupling" state as well. A timespan is provided for which both coupler heads shall remain in the "prevent recoupling" state. Controllers on the wagons shall set the coupler heads into "ready to couple" mode when the timer has elapsed. This is done autonomously by the wagons, i.e., a connection to the locomotive is not required.

The advantages of this approach are as follows:

- This approach can be applied to all marshalling yards in Europe, whereas decoupling in the entrance group requires a suitable hump topology that is not always present.
- This approach does not reduce humping speeds and allows high speed approaches at the same time.
- Setting the "prevent recoupling" state to "ready to couple" does not require a new interface to the wagon or a robotic/mechanical solution behind the hump. It can be achieved quite simply with software and actors on the wagons that are required anyways (for a DAC5).

5.2.2.2 Specific Concepts for Decoupling Wagons in Hump Yards

With the introduction of the DAC and the DAC5 in particular, a transformation of the hump yards and the shunting processes is necessary. However, since the conditions and the equipment of each yard vary greatly, different solutions must be developed to provide at least one that is feasible for each yard.

The following criteria regarding available equipment are particularly relevant to which solutions can be applied to which yard:

- Digital dispatching / YMS
- Digital maps
- Automatic remote controlled humping locomotives (including localization of locomotive)

The economical aspect of a transformation should not be disregarded either. While some operators have both the desire and the means for the transformation of yards, others simply wish to continue operation with minimal investment. To encompass all these different stakeholders the following ideas/use-cases were conceptualized:

5.2.2.2.1 Concept 1: Decoupling by loco driver, commands given by voice radio

The driver drives the loco while the shunting staff is positioned at the hump or has a live view of the hump. The shunting staff determines visually when to decouple the wagons and gives the command via voice radio to the loco driver. The loco driver then enters the command via an HMI to the DAC controller.

Since the feasibility of this idea is doubtful, it will not be considered in detail in the future.

Advantages:

- Low investment

Disadvantages:

- Visual determination of when to decouple requires experience.
- Feasibility of this doubtful, as the delay between the shunting staff and the loco driver is significant.
- Overburdening of loco driver is likely.

Suitable situations/yards/operators:

- Possible with bare minimum of investment
- Usable as a fall-back solution if more complex systems (dispatching / YMS, automatic loco) fail, while still avoiding manual interaction with the wagons

5.2.2.2.2 Concept 2: Remote decoupling by personnel

The driver drives the loco as usual, while the shunting staff on the hump is equipped with a mobile device. They visually determine when to decouple the wagons and then enter the command in the mobile device. The mobile device sends the command directly to the loco, which sends the command to the corresponding couplers.

Advantages:

- Low investment
- Operational process very similar to the current one, if the decoupling takes place approaching the hump.

Disadvantages:

- Visual determination of when to decouple requires experience.
- Radio connection between mobile device and loco necessary.

Suitable situations/yards/operators:

- Possible with bare minimum of investment.

- Usable as a fall-back solution if more complex systems (dispatching / YMS, automatic loco) fail, while still avoiding manual interaction with the wagons.

5.2.2.2.3 Concept 3: Assisted remote decoupling by personnel

The driver drives the loco as usual, while the shunting staff on the hump is equipped with a mobile device. The locations where each wagon should be decoupled is calculated in advance using data from the dispatching / YMS system. Markers on the hump display “zones” to which each decoupling location is assigned. When the wagon pair reaches its assigned zone, the shunting staff enter the decoupling command in the mobile device. The mobile device sends the command directly to the loco, which sends the command to the corresponding couplers.

Advantages:

- Low investment
- Operational process very similar to the current one, if the decoupling takes place approaching the hump.
- No visual determination/estimation of when to decouple necessary; It is calculated by a system.

Disadvantages:

- Digital dispatching / YMS and interface between it and mobile device necessary.
- Radio connection between mobile device and loco necessary.
- Zone markers on the hump necessary.
- Calculation of decoupling location possibly difficult (tank wagons, loose loads, false information in system, …).

Suitable situations/yards/operators:

- Possible with low investment

5.2.2.2.4 Concept 4: Remote driving and decoupling by loco driver

The loco driver is out of the loco, standing on the hump and driving the loco with a remote control. They visually determine when to decouple the wagons and enter the command via either a separate mobile device or an add-on to the remote control.

Rather than relying on a visual determination of the decoupling locations, this approach could be combined with some of the other ideas where the decoupling locations are calculated.

Advantages:

- Low investment
- One-Man operation possible.

Disadvantages:

- Visual determination of when to decouple requires experience.
- Remote control for the loco necessary.
- Radio connection for the decoupling also necessary.
- Risk of "over-working" the loco driver (a lot of things to do at once).

Suitable situations/yards/operators:

- Possible with low investment
- Might be usable in special cases as a fall-back solution if more complex systems (dispatching / YMS, automatic loco) fail.

5.2.2.2.5 Concept 5: Unsupervised decoupling and driving by loco driver, command based on traction force

The driver drives the loco as usual, however, there is no staff on the hump. The loco measures the traction force of the loco and indicates to the loco driver when the traction force is in decoupling range. The driver then enters the decoupling command via an HMI.

Since the feasibility of this idea is doubtful, it will not be considered in detail in the future.

Advantages:

- One-Man operation possible
- Generic solution that does not require any outside equipment or interfaces

Disadvantages:

- Feasibility doubtful, as it is unknown how well you could determine the decoupling moment by traction force, especially for long trains.
- Overburdening of loco driver is likely

Suitable situations/yards/operators:

- Possible only if the traction force curve for humping is known

5.2.2.2.6 Concept 6: Unsupervised decoupling and driving by loco driver, command based on train length

The driver drives the loco as usual, however, there is no staff on the hump. The split positions are calculated and transmitted to the loco. The driver sees this in an HMI and selects the point of separation in the HMI. On the side of the tracks some sort of length flag or other type of indicator indicates the distance to the top of the hump. When the loco driver passes the corresponding distance indicator, they execute the decoupling command. Optionally, as there is no staff on the hump, this process could be supervised remotely by staff using e.g., live cameras on the hump.

Advantages:

- Low investment
- Single-staffed operation possible

Disadvantages:

- Digital dispatching / YMS with connection to loco necessary
- Distance indicators on the side of the track necessary
- Risk of "over-working" the loco driver (a lot of things to do at once)

Suitable situations/yards/operators:

- Possible with low / medium investment

5.2.2.2.7 Concept 7: Decoupling by on-board system (TRUST5)

The driver drives the loco as usual. The split positions are calculated in advance. A decoupling system on board of the loco observes its current position and velocity and decouples the wagons automatically at the correct location.

Advantages:

- One of the easiest for the staff and the most efficient for the process.

Disadvantages:

- More investment necessary than most of the other options.
- Digital dispatching / YMS with connection to loco necessary.
- Reliable Localization of the loco necessary.

Suitable situations/yards/operators:

- Suitable for larger yards with pre-existing infrastructure and the available resources to upgrade their locos.

5.2.2.2.8 Concept 8: Decoupling via yard automation system

This use-case aims to summarize already fully automated yards with yard automation systems. The loco drives autonomously, controlled by this yard automation system, while the decoupling commands are also given by the yard automation system, based on pre-calculated decoupling positions and the loco position and velocity.

Advantages:

- One of the easiest for the staff and the most efficient for the process.

Disadvantages:

- High investment if no hump control system is present.
- Development and integration of new interfaces into exiting systems necessary if a hump control system is present.

Suitable situations/yards/operators:

- Most fitting solution for already automated yards.

5.2.2.3 Summary

The advantages and disadvantages of these concepts are summarized according to the following criteria:

- **Feasibility**: How likely it is that this concept could actually be used in real operations.
- **Cost**: How large the investment in new equipment would have to be.
- **Burden on Staff**: How difficult the work would be for staff members and the risk of overburdening them.
- **Required Infrastructure**: The cost and complexity of infrastructure elements and surrounding systems, such as digital dispatching systems, required to make this work.

Each concept is judged by how "good" it is in each of these criteria. That means that e.g., low cost and high feasibility would both receive a +, while a lot of required infrastructure would get a – and an average burden on staff would get a ~.

Table 12: Evaluation of the different concepts for hump shunting

Concept	Name	Feasibility	Cost	Burden on Staff	Required Infrastructure
1	Decoupling by loco driver, commands given by voice radio	-	+	-	+
2	Remote decoupling by personnel	+	+	~	+
3	Assisted remote decoupling by personnel	+	~	+	~

4	Remote driving and decoupling by loco driver	~	~	-	~
5	Unsupervised decoupling and driving by loco driver, command based on traction force	-	~	-	+
6	Unsupervised decoupling and driving by loco driver, command based on train length	+	~	-	~
7	Decoupling by on-board system (TRUST5)	+	-	+	-
8	Decoupling via yard automation system	+	-	+	-

The conclusion of these results is that the concepts 1 and 5 will not be considered in greater detail in further development due to their low feasibility. Solutions that are unlikely to work reliably are unsuitable for the purposes of shunting yards.

5.2.2.4 Goals for Development

The goal is to develop conceptual solutions for decoupling with a DAC5 for all hump yards in Europe. As mentioned before, each yard varies greatly in terms of available equipment, ambition to automate and available financial resources. While the described use-cases attempt to cover everything, they are in the end only a part of a complicated process and still flexible to be adapted to local conditions. The remote/automatic decoupling is meant to be only a module that can be combined with other features, like automatic shunting, but should also function independently.

To allow operators to adapt the processes to their relevant conditions, and to help development as well as maintain modularity between the complex components of a yard, certain interfaces need to be specified. From the described use-cases three interfaces that require such specification were identified:

- The interface of the DAC Controller
    - Transmitting wagon status and command replies
    - Receiving decoupling and other commands
- The interface of the YMS/Dispatching

  - Transmitting the split list, wagon data, yard topography and decoupling positions
  - Receiving train status
- The interface of the mobile device
  - Transmitting decoupling and other commands
  - Receiving train status

Defining these interfaces is most likely a shared responsibility between the Train Functions expert group and the Decoupling expert group. The aim is to define a high-level set of information and functions exchanged via these interfaces with which all the use-cases can be covered.

Concepts 2 and 8 will be followed in subsequent sections of this deliverable as they represent suitable solutions for both ends of the spectrum. Concept 8 addresses highly automated yards and allows fully automated decoupling. Concept 2 offers a low-cost solution allowing continuous operation after the introduction of the DAC 5. The concept is therefore suitable for marshalling yards with hump that are in poor or outdated condition regarding automation. Requirements for both concepts are derived in section 5.4.3, a detailed architecture description can be found in section 5.3.1.

5.2.3 Flat Yard Operation

5.2.3.1 Introductory User Story

This description of this operational concept starts with a "User Story" to describe a zig-zag movement which is initiated by the trackside device (ASO trackside) according to a defined plan to move wagons from one location to another. The shunting composition has to move from track 2 to track 1, see Figure 9.

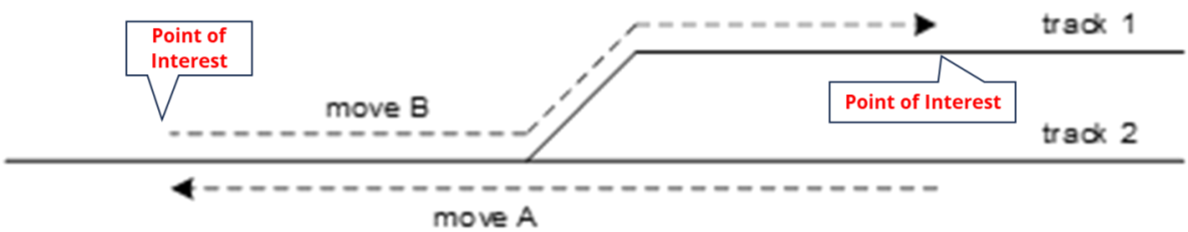


Figure 9: Zig-zag move

It is assumed that the TU is equipped with a ASO on-board device. The ASO mission of the TU might be executed with or without wagons coupled to it, including execution of all required "train functions".

Concerned Use cases:

This mission refers to the Use-cases UC17 (TP08) Flat shunting – Pickup and UC16 (TP07) Flat shunting – Delivery.

Starting point:
The traction unit (TU) is located on a defined track (defined within the ASO trackside), at an exact position with a recommended accuracy of +/- 0,5 m.

Task:
The TU moves along a defined distance to a defined (planned) exact destination point of interest. This point of interest might be:

- beyond a switch to change direction and to change tracks
- to pick up a wagon (Coupling point)
- to drop off wagon(s) (Decoupling point)

Preconditions:

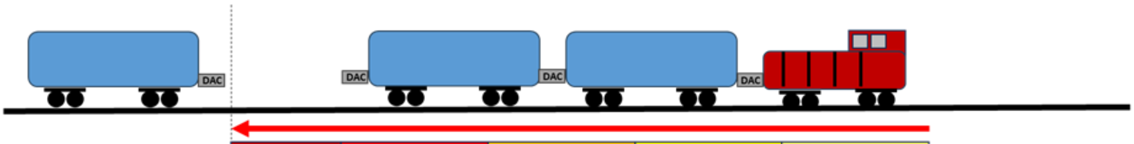
An important precondition for this scenario is the knowledge of the location of each wagon within the yard. This location can be calculated by knowing the exact location of the TU in combination with the wagon data coming either from the TAF/TSI wagon data base and the train function data (composition detection) via the lead-CCU when the TU is coupled to the wagon consist. The train data are delivered via lead-CCU and ASO to the YAS / YMS where the calculation and administration of the wagons and their appropriate location takes place.

The location (position) of the TU must be known at any time (both ends with the required accuracy). Therefore, the location of each wagon can be calculated in relation to the known location of the TU after stopping and before uncoupling. Finding the location of a wagon may in addition to this calculation be supported by positioning systems available on wagonside.

The required moving distance of the TU is calculated according to the planned wagon position or change of direction (see tasks).

The point of interest for a wagon has to consider the free coupler (uncoupled coupler) of a wagon, which is the first/front wagon in pushed direction or the last/rear end wagon in pulled movement.

The maximum “constant” shunting movement speed can be chosen according to local requirements. The reduction on approaching to the point of interest (reversing or coupling point) in fixed steps according to local regulations. An example is depicted in the following figure, assuming a maximum speed of 40 km/h and a touching speed for the DAC for coupling of 2 – 5 km/h.



	2-5 km/h	10 km/h	15 km/h	20 km/h	40 km/h	
	20 m	50 m	50 m	50 m	50 m	
+/-	0,5 m	1 m	1,5 m	2 m	2 m	Recommended position accuracy for ASO TU

Figure 10: Speed according to distance and recommended position accuracy

All process steps of the use-cases, including "train functions" shall be supported on one HMI display (YMSmobile). Operational requirements for the YMSmobile are presented in chapter 5.5.2.

Process steps other than those defined in D2.1:

1. TU Operator or YAS requests movement authority (MA) from signaller.
2. Signaller puts all movable objects (e.g. points, derailers) in the appropriate position and gives the MA, TU operator or ASO executes the movement of the TU. The operational scenarios include (among others):
    a. TU performs the movement A according to the information on the DMI. It includes putting the direction controller in the right position for this movement, which is indicated on the DMI (forward/backward).
    b. TU stops after clearing the point, latest at the EOA.
3. Trackside detects that the shunting composition has stopped at the right location (e.g. point is cleared) and prepares the track for the next part of the zig-zag move, e.g. change point position.
4. The TU operator or the ASO on-board requests a new MA. Trackside (ASO / YAS) sends the relevant MA for move B to the TU (ASO on board).
5. The MA is shown on the DMI with the direction opposite from the previous move.
6. TU performs the movement B in the opposite direction. It includes putting the direction controller in the right position for this movement, which is indicated on the DMI (forward/backward).

5.2.3.2 Free Shunting movements within limited area

5.2.3.2.1 Non-automated operation:

This scenario describes movements in both directions for which the driver is free to move within a defined area, see Figure 11.

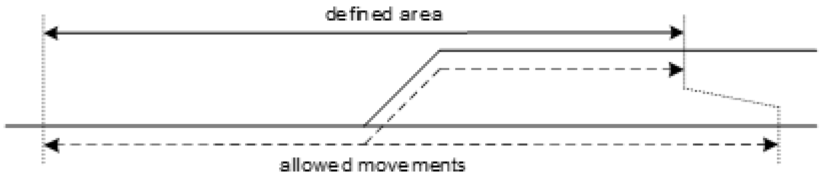


Figure 11: Free movement in a defined area

The operational scenarios include (among others):

a. Multiple movements within a defined area on the main line or within the yard such as for re-marshalling of freight wagons.
b. Movements into and out of a stub track.

The train has arrived (e.g., as a planned train movement with an MA) in the area. Trackside defines the limits of the area in which the train will be allowed to move in both directions and will ensure that no MA will be given for any other train to enter this area. Because the trackside does not know when and in which direction the vehicle wants to move, the trigger for the movement has to come from the TU operator (driver or another nominated person).

There may be movable objects (e.g., points, derailers) in the defined area, which are operated locally during this scenario. Local control of points could be part of the central safety system using in/outputs from a local system (e.g., using a remote device which is connected to the central safety system). Lock/unlock of the movable objects is then possible. In that case the trackside needs to define the limits to all specific tracks which are included in the area.

If the points are not operated locally, the TU operator or other staff in the area should communicate to the signaller when they want the point position to be changed.

By operational procedure the TU operator is aware that the train is in an area where the driver can take the initiative to move his train.

When the shunting activities in the defined area are finished, the trackside revokes the limits and treats the area again in the same way as before the limited area was defined.

5.2.3.2.2 Automated operation:

This scenario is nearly the same as described in the user story (previous chapter 5.2.3.2.1). The only difference to this scenario is:

- The TU operator might stop at a convenient location. This does not need to be the end of his MA. It could for instance be after clearing a point through which a next movement in the opposite direction has to take place.

<u>Description Drop Off (Delivery) and Pick Up</u>

Both processes are described in detail in D2.1 (TP07 Flat Shunting Drop Off and TP08 – Flat Shunting Pick Up).

5.2.4 Reference to Train Functions for ASO

FDFT Traction Unit Base System functional architecture will be shown in D3.1 to highlight the functional aspects, whereas all physical and data aspects of those connections will be covered through the planned deliverables /WP3_3.2/ and /WP3_D3.3/.

The FDFT base system shall have an Interface to the F-TCN, allowing the onboard devices to communicate with other network participants using the F-TCN. Details on physical and data access will be described in /WP3_D3.2/ and /WP3_D3.3/ 9.2.2 Power Distribution line in traction unit.

The power distribution line is planned to be based on 400 V AC. Details on physical access will be described in /WP3_D3.2/ and /WP3_D3.3/

Uncoupling control: The function allows to engage the electric actuator of the M-Coupler, resulting in uncoupling the DAC between two adjacent wagons or the TU and the wagon consist. Which adjacent wagons to be uncoupled will be specified by an appropriate command provided by the lead-CCU. The uncoupling function shall be performed on both M-Couplers simultaneously in order to reduce mechanical wear of the coupler. All physical and data related details will be defined in /WP3_D3.2/ and /WP3_D3.3/. 9.2.5.2

Prevent coupling control: The function allows to engage the electric actuator of the MCoupler, resulting in preventing automatic coupling with the adjacent wagon's coupler. The prevent coupling function shall be performed upon command and shall be released, if certain conditions are met (conditions not yet specified). The prevent coupling function shall be performed on both M-Couplers in such a way that mechanical wear of the couplers is minimized. All physical and data related details will be defined in /WP3_D3.2/ and /WP3_D3.3/.

The local HMI device interface of the TU allows access to the functionality of the traction unit base system. This allows the TU operator to make use of the functionality provided by the traction unit base system.

The local HMI device and the related interface requirements will be specified in /WP3_D3.2/ and /WP3_D3.3/. 9.2.8 FDFT-Link interface

The traction unit allows access to the functionality of the traction unit base system via the FDFT-Link. This allows any FDFT-System to initiate all activities as given by the operational procedures. In addition, the FDFT-Link interface allows the FDFT Base System of the TU to send the process & status data as captured by the traction unit base system itself or captured by the wagon / consist base systems and transferred via the F-TCN to the traction unit. It will be ensured that only one acting FDFT system or user at a time, is able to get access. The FDFT-Link interface and the related interface requirements will be specified in /WP3_D3.2/ and /WP3_D3.3/

The traction unit collects information from all wagons / consists in train, foremost from the last wagon / consist in train, to perform the train integrity detection function. The train integrity detection support and the related interface requirements will be specified in /WP3_D3.2/ and /WP3_D3.3/. 9.2.10

Train composition detection support: The traction unit based function collects information from all wagons / consists in the shunting composition to derive the actual composition. The train composition detection and the related interface requirements will be specified in /WP3_D3.2/ and /WP3_D3.3/. 9.2.11

Train length determination support: The traction unit based train function provides the length of the TU and consists coupled to it, and forwards this information to the requesting function (e.g., Train length determination voter). The train length determination support and the related interface requirements will be specified in /WP3_D3.2/ and /WP3_D3.3/.

5.3 System Architecture Description

5.3.1 Yard Architecture

The Yard Automation system architecture can be logically and physically divided in two components: the trackside system and the traction unit on-board system.

Figure 12 shows, in a simplified manner, the relations among the Yard Automation system (in blue) and the main line system (in red).

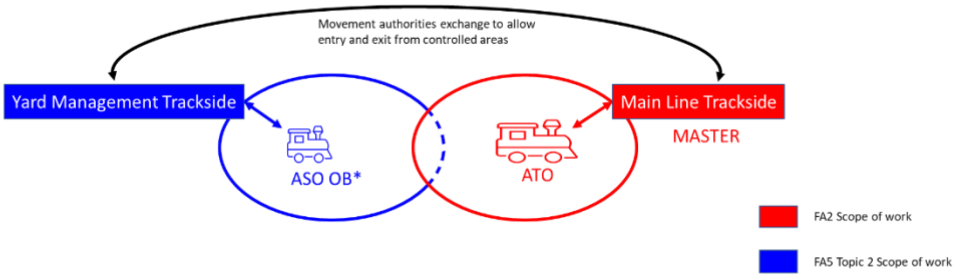


Figure 12: ATO – ASO simplified architecture

ASO on-board is basically an evolution of existing Remote Control of Locomotive systems able to execute missions defined at Yard Management Trackside system level and able to operate the Digital Automatic Coupler.

ATO locomotives will run mainly in the area controlled by the Main Line Wayside manager. When an ATO locomotive will need to perform operations in the yard two actions will be performed:

1. Yard Management Trackside to give movement authority to the ATO locomotive to enter in the yard through a vital hand-shaking with the Main Line Trackside system (as an example this is the typical interaction between interlockings);

2. ATO will switch to Remote Control mode when entering the yard to be managed by the Yard Management Trackside system. De facto the ATO entering in a yard area will act as a ASO locomotive.

ASO traction units usually operate only in the freight yard areas and in last mile sections. When an ASO traction unit need to operate in main line areas they will be remotely controlled in degraded mode as described in the ATO specifications. Obviously even in this case the Yard Management Trackside manager needs to ask moving authority (i.e., routes) to the Main Line Trackside manager.

A more detailed (still high level) architecture of the Yard Automation & Management System is shown here:

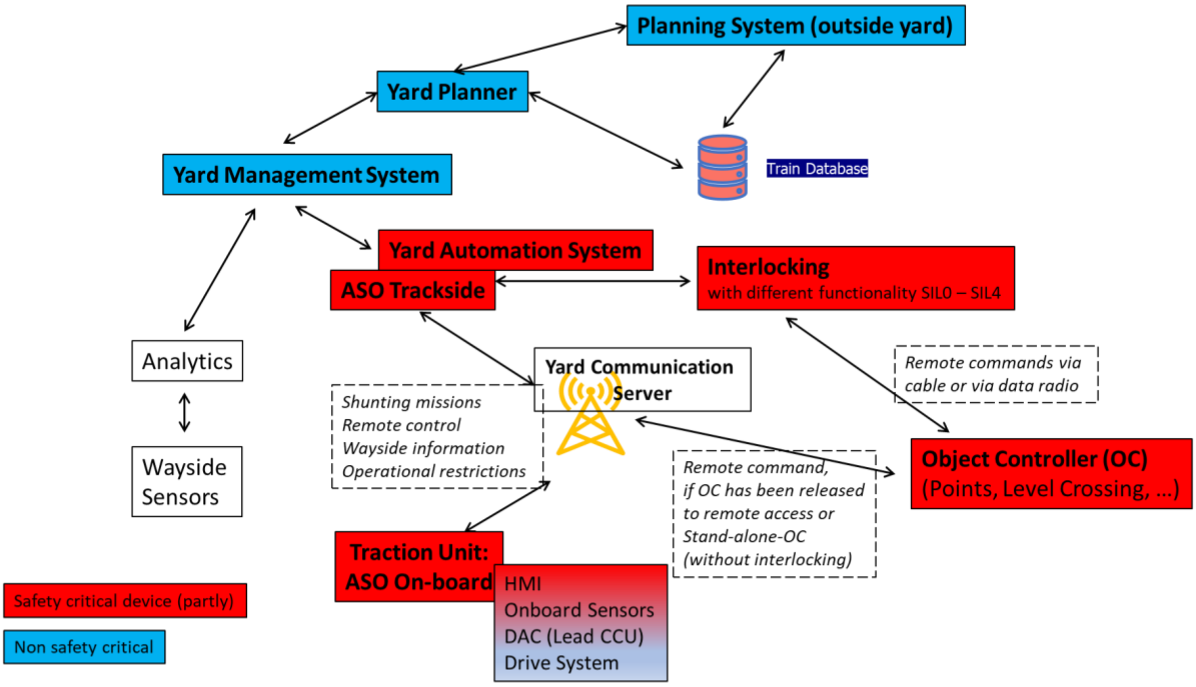


Figure 13: Yard Automation & Management System Architecture

It is important to underline that intentionally the ASO is split between the ASO on-board and the ASO trackside (Master). This division in two subsystems is critical to ensure that the complexity of yard operations is managed only in one centralized place. As a matter of fact, we are dealing with freight yards operations which are not standardized across Europe (and world-wide), this resulting in a heterogenous variety of different uses cases. At the best of our knowledge there is no literature which classifies such heterogenous variety of uses cases and the work to perform such classification is considered prohibitive and time consuming with the high risk to being unable to include all cases. The solution to the lack of standardization in freight yard operation and the need to develop a standard solution allowing for a smooth and economically sustainable migration plan suggested the following master and slave approach where:

1. The traction unit (shunting locomotive) is the slave, remotely controlled in a standardized manner and with standard protocols. In this way any traction unit (and any ATO locomotive embedding the same standard remote control) can operate in any yard in an interoperable way. This

approach aims at developing one stable version of the ASO on-board avoiding the need of several software and hardware releases when discovering new use cases coming from yards not considered previously.

2. The ASO trackside (Master) will be a configurable and customizable tool which will take into account the specific yard operations.

As anticipated above current freight yards are characterized by a quite large variety of level of automation and complexity: from flat yards completely manually operated both trackside and on-board (including manual operation of mechanical switches) to the most advanced hump yards equipped with automatic remote control of traction units (by the electronic hump control system); interlocking systems, retarders etc. Even the data flow among the different operators in the yard can have very different level of automation (form paper-based processes to paper-less ones).

In such a heterogeneous context we proposed a modular architecture which allows a gradual evolution of the freight yards depending on the starting point and the business case.

Please find below some diagrams showing how the application of several modules (all aligned with the high-level architecture presented before) concur to evolve from GoA0 to GoA4.

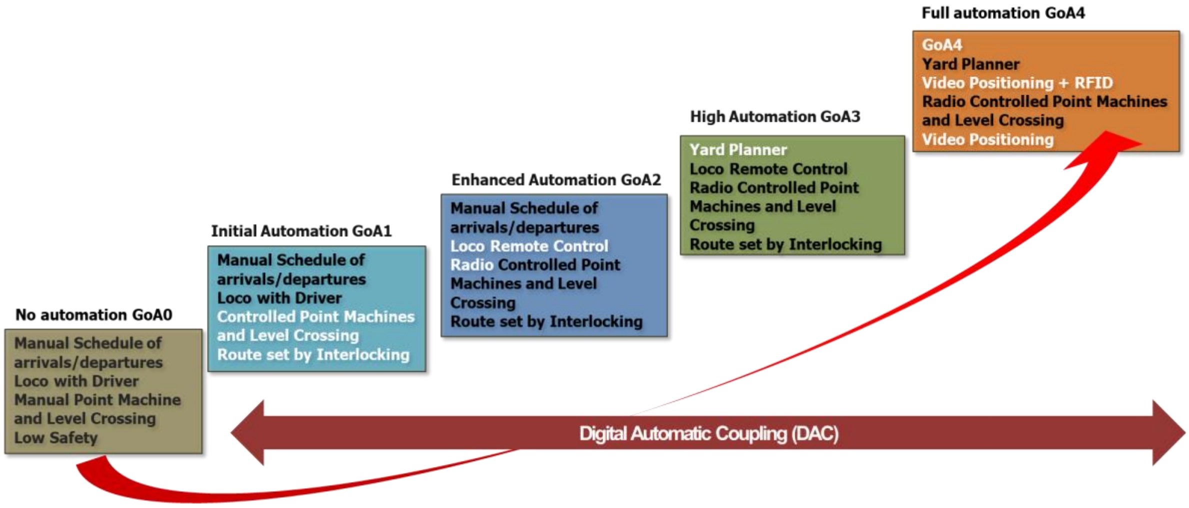


Figure 14: GoA approach in Yards

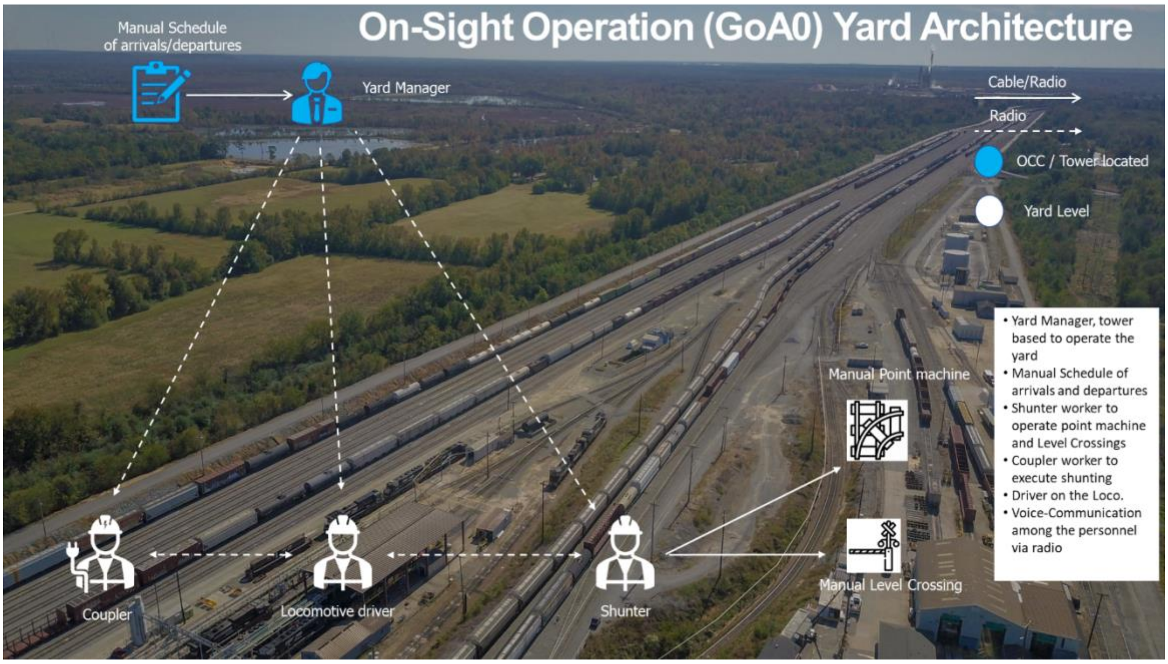


Figure 15: On-Sight Operation (GoA 0) Yard Architecture

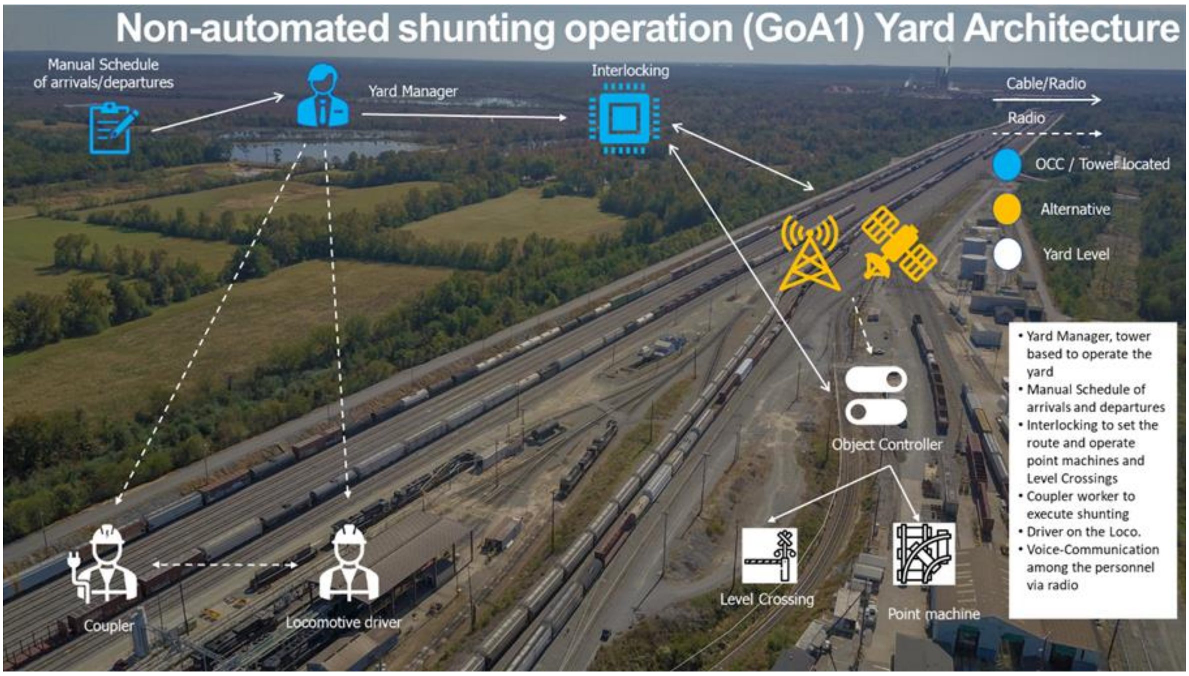


Figure 16: Non-Automated shunting operation (GoA1) Yard Architecture

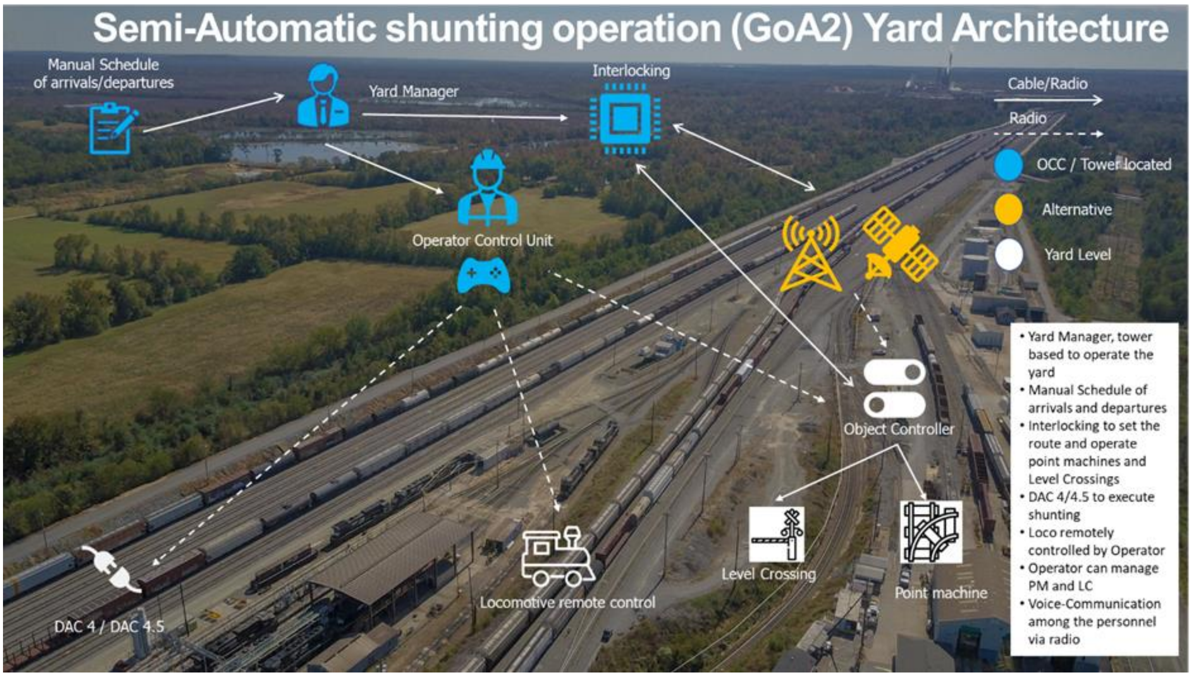


Figure 17: Semi-Automated shunting operation (GoA2) Yard Architecture

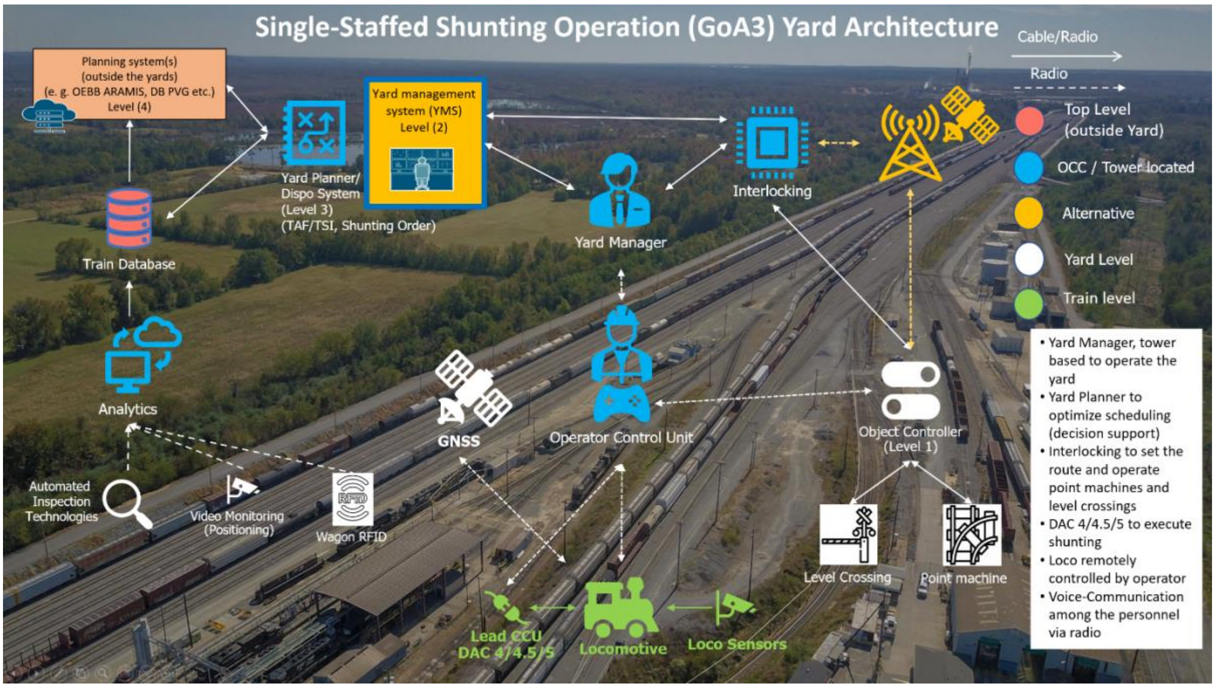


Figure 18: Single-staffed shunting operation (GoA3) Yard Architecture

Figure 19: Unattended shunting operation (GoA4) Yard Architecture

According to Deliverable 2.1 Preliminary Operational Procedures V1.0 [2], the FDFT Yard systems is part of the following overall architecture.

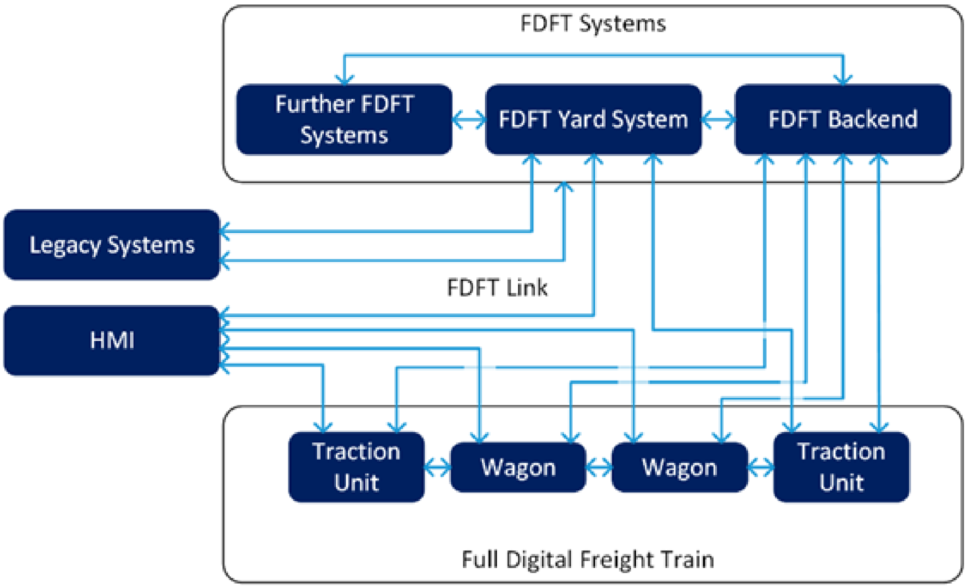


Figure 20: FDFT Links

The yard architecture as such distinguishes between different levels, planning and execution, which reflect different levels of abstraction also in the time sequence from the superordinate planning to the operational execution of the shunting movements to be carried out. Starting with the higher-level planning, which is also based on capacities, and increasingly yard-specific conditions, the sequence of activities to be carried out is planned and operationally implemented.

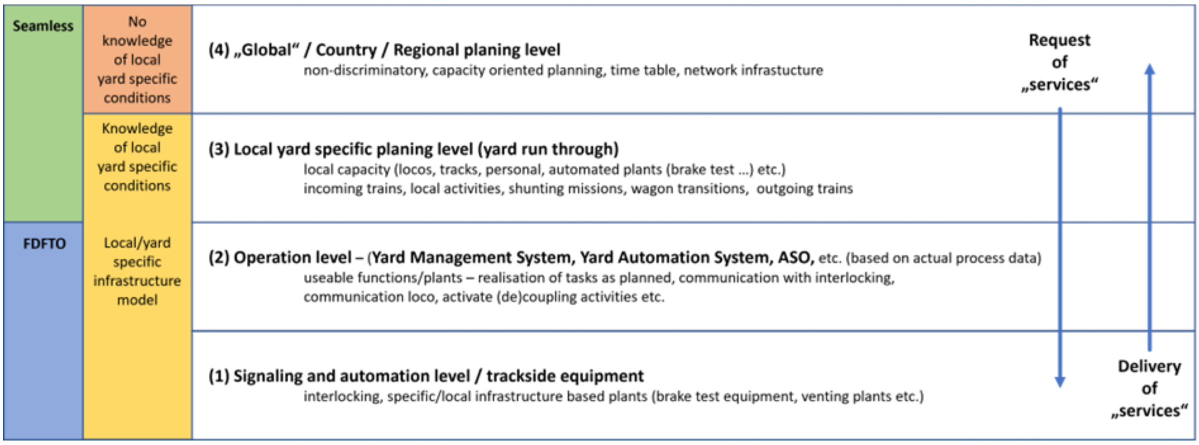


Figure 21: Levels of planning and executio

The FDFT Yard System consists of the following components shown in the diagram.

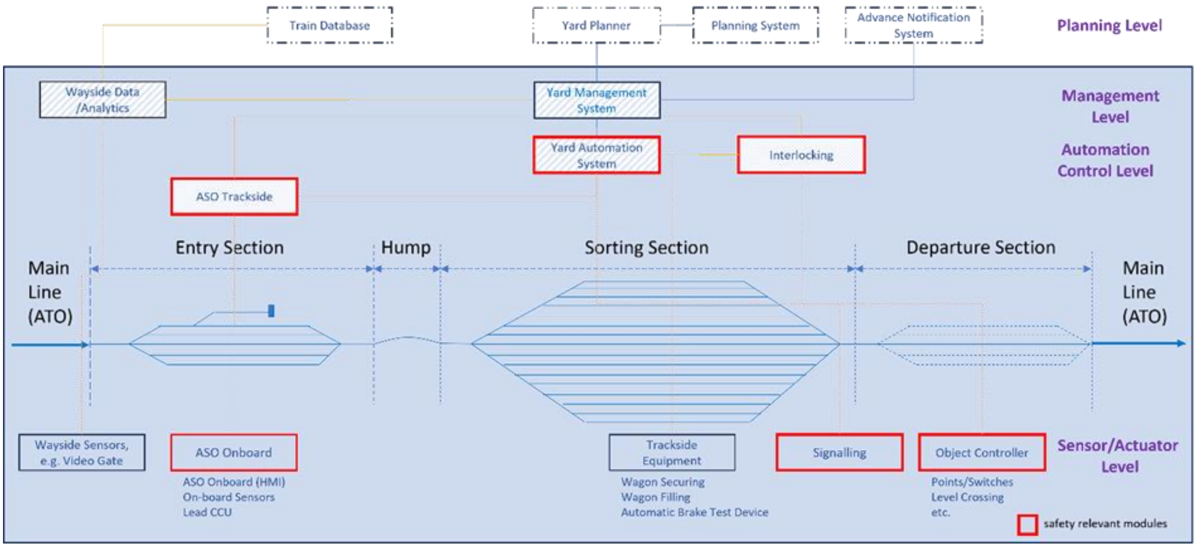


Figure 22: FDFT Yard System

In the diagram, a hump yard is used as an example, as the specific features of this yard type are also shown there. This can also be considered as a constellation for flat yards, as certain shunting missions are also used in both flat and hump yards.

The Yard Management System (YMS) and the Yard Automation System (YAS) together form the Yard Management and Automation System (YAMS). The Yard Automation System is mainly a (hump) shunting yard interlocking system, while the Yard Management System (YMS) supports the superimposed operational implementation of the activities planned by the Yard Planner. The YMS is not a safety relevant system.

The Advance Notification System as a part of YMS notifies the trains that will/should reach the marshalling yard in a following defined period of time. Data concerning the train configuration, the cutting list, etc. are provided accordingly.

The Automatic Shunting Operation System (ASO) is the system responsible for the safe execution of the intended shunting missions. It consists of an ASO trackside component and ASO onboard components on the traction units. Depending on the current situation, the ASO receives its tasks from the Yard Management System (YMS) or from the Hump Yard Shunting Interlocking. In addition, the ASO provides a way to communicate with the Traction Unit via the lead CCU on the Traction Unit using the Train Functions.

In addition, there may be other systems in the yard that serve, for example, to recognize the position of the vehicles or provide additional functionalities such as automatic brake testing, etc. These systems are then also connected to those of the YAMS in order to be able to control them and record their data and status and visualize them.

5.3.2 Decoupling in hump yards

This section describes the design of solutions allowing decoupling in marshalling yards with hump. Design statements are in accordance with the technical requirements specified in section 5.4.3.

5.3.2.1 Scope of architecture

The described solutions are limited to trains completely equipped with the DAC type 5 and decoupling in movement in the hump area.

The design makes use of basic train functions implemented on the intelligent freight train. These train functions, required for decoupling, are specified in Deliverable 5.1 and are outside the system boundary. The design description in the subsequent sections focuses on additional functions both on the locomotive and the infrastructure side required to control decoupling in the operational environment of a hump yard.

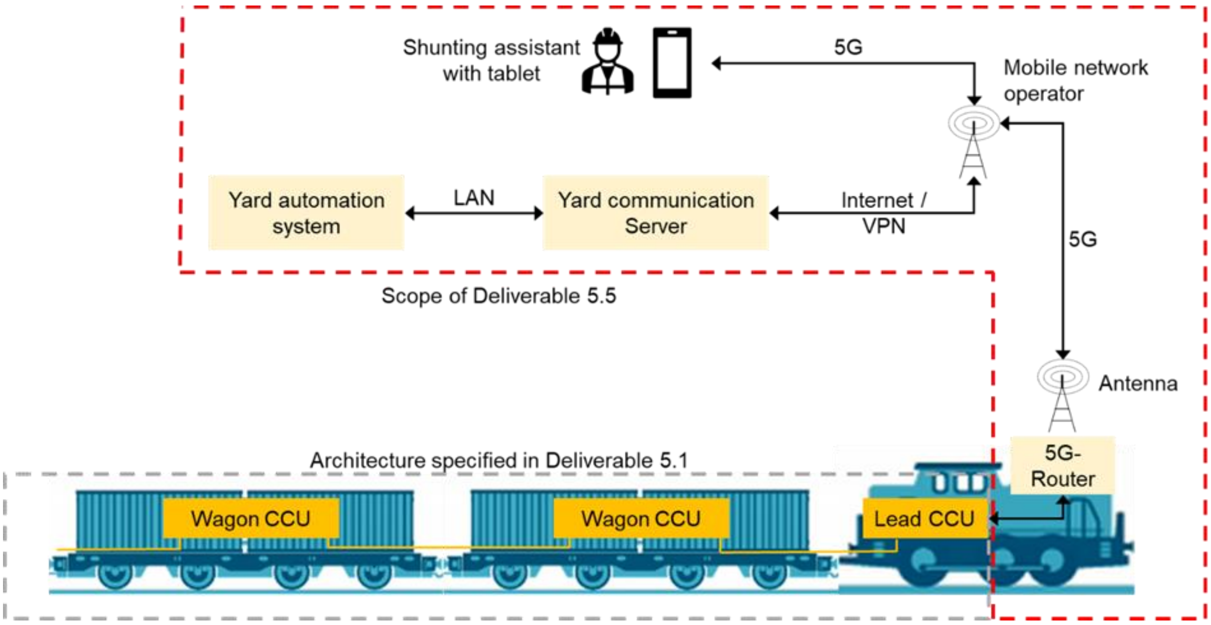


Figure 23: System boundaries

5.3.2.2 Constraints of the intelligent freight train

With the introduction of the DAC type 5 to rail freight including supplementary components on the wagons such as CCUs or automatic parking brakes, challenges for the operation of hump yards change. The newly introduced components are enablers for automation of processes but also come with constraints. A brief overview regarding the impact of these constraints on hump yards is given in the following paragraphs.

Decoupling of wagons is not possible when both coupler heads are under tensile forces which is a comparable behaviour to the screw coupler. During hump shunting, a wagon (group) is pushed over the hump. Due to trackwise components of gravity force in a slope, decoupling is only possible up to a specific point. If the wagon (group) was pushed further over the hump, the coupler heads in question would experience tensile forces as wagons at the slope are pulling more towards the classification tracks than to the entrance group.

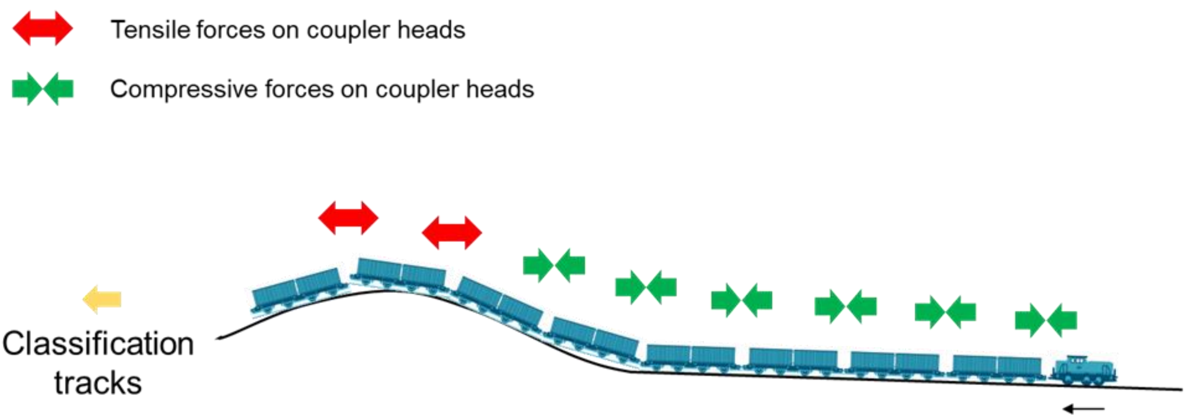


Figure 24: Forces on coupler heads during hump operation

During the decoupling action, both coupler heads are involved i.e., actuators on both coupler heads have to drive their locking mechanisms into an unlocked position. Otherwise, one coupler head may remain in coupled position which may cause abrasive wear during the next coupling action. Addressing both coupler heads of the DAC type 5 is solved by software of the intelligent freight train. Thus, no solution needs to be found in this deliverable.

After a completed decoupling action, both coupler heads will couple again when they first separate and then reapproach. This can happen any time during hump shunting e.g., due to wagons with swashing liquids or varying speeds of the humping locomotive. To overcome this issue, there is a feature on the intelligent freight train, called “prevent recoupling”. The actuators will keep the decoupling mechanisms in an unlocked position where recoupling is not possible. The actuators first drive the mechanisms back into the position allowing to couple when a chosen timespan has elapsed. This timespan needs to be chosen so that it lasts at least from the moment of decoupling to the actual separation of the wagon group on the hump. On the one hand, this prevents unintentional recoupling on the hump, but allows automatic coupling in the classification tracks.

The 400 V/AC powerline supplies the wagons with electrical energy required for charging of the batteries. The wagon CCUs and all actuators on the wagons rely on battery power. During the decoupling action, named powerline must be deactivated on the locomotive. Otherwise, electric arcs may occur between the contacts of the e-coupler that will damage the pins.

As stated before, the hump shunting process relies on battery power which can limit the availability of functions. Batteries are required to have a sufficiently high state of charge allowing the wagon to perform the required steps without external feeding of electric energy.

Wagons can be equipped with an automatic parking brake that can be activated or deactivated via commands of the intelligent freight train. This feature is particularly useful in the entrance group of hump yards, when wagons are parked over several hours or even days. Today, brake shoes, manually set by staff, are used to prevent unintentional movements of parked wagons. Before the parked wagons are pushed to the hump for sorting, it has to be ensured that all parking brakes are deactivated.

When wagons roll down the hump, driven by forces of gravity, free running characteristics are required. Today, parts of the air brake are disabled manually by staff. This process will be automatised in the future. The option, currently discussed in the TRANS4M-R project can be described as follows: A valve located on the C-hose between the brake cylinder and the air control valve can be shut. At the same time, the part of the C-hose leading to the brake cylinder is vented to ambient pressure. Control of this additional valve is done by software functions of the intelligent freight train. The valve should be closed ideally just before the decoupling action on the hump, allowing the train to be pushed onto the hump with full brake capabilities but allowing free running characteristics during the subsequent sorting phase.

The intelligent freight train has two modes: the FDFT shunting mode and the FDFT train run mode. Named functions like decoupling with prevent recoupling, activation/deactivation of parking brakes or disabling the brakes are only available in FDFT shunting mode. The FDFT shunting mode is the default mode. The train run mode has to be selected before the start of a train run on the mainline and is deactivated upon arrival in the entrance group in order to decouple the mainline locomotive from the wagon set. Decoupled wagons remain in FDFT shunting mode. Hence, there is no need change the mode during shunting activities as long as they are performed according to the defined processes.

5.3.2.3 Variants of solutions

The solution bases on remote controlling the basic train functions of the intelligent freight train in the entrance group, during approach to the hump and during the humping phase (See 5.2.1.1). This remote control is done either by systems or staff that control the processes in hump yards allowing the basic train functions to be executed in such a sequence that the aimed operational goals can be achieved.

The technical equipment of European hump yards varies widely: From yards with modern highly automated equipment with several thousand wagons per day, pushed over the hump, to smaller sites with out-dated equipment where only few trains per week are being processed. Consequently, there must be several solutions that fit to the existing equipment, the expected reduction in manual labour and the financial capabilities of the owner.

In the following paragraphs, two variants are briefly introduced whereas functional and technical details follow in the subsequent sections.

5.3.2.3.1 Variant for lowly automated yards

A variant for hump yards with a low technical standard is provided.

These yards can be characterised as follows: Typically, they experience only low traffic. A few trains enter or leave the yard per day, or they are only occasionally in use. Point control systems are relay-based and have been installed between the 1950s and 1970s. The yards have either retrofitted retarders with simple control logic or lubricated brake shoes are used in order to brake the wagons entering the classification tracks. These types of yards are still in use as for sorting of wagons, humping is more time-efficient than flat shunting. However, due to a lack of financial investments, modernisation to state-of-the-art technology could not be realised in the past. It is therefore rather unlikely that large sums will be spent for more sophisticated solutions allowing automatic decoupling. The intention of this variant rather is to provide a simple solution enabling a continuation of the hump operation and still allowing operators to benefit from the improvements due to the intelligent freight train.

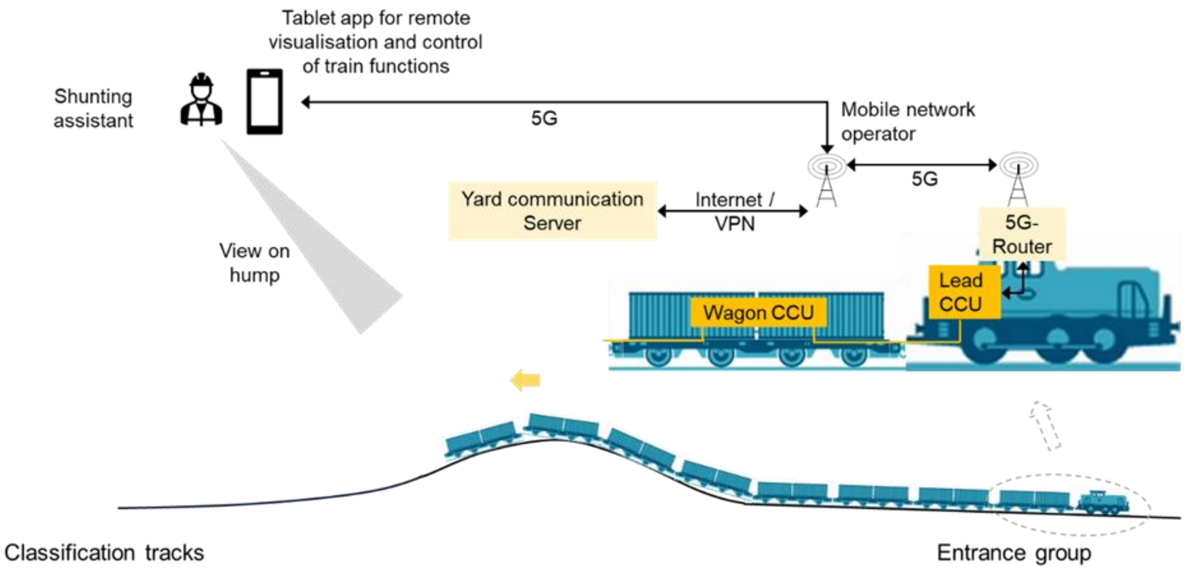


Figure 25: System architecture for lowly automated yards

The system consists of a wireless link between the Lead CCU and a network on the infrastructure side. Decoupling is conducted by a shunting assistant equipped with a tablet that is also connected to named network. The shunting assistant has a visibility to the hump, i.e., he or she may be standing on the hump but also a remote location with visibility via cameras may be feasible. The shunting assistant doublechecks the train composition with the cut list, prepares the humping operation and decouples the wagon or wagon group on the hump while the locomotive is pushing with a low but speed. This task is in principle the same as today, where the shunting assistant throws out the screw couplers with a stick. Manual preparatory work in the entrance group or physical work on the hump can be omitted. The advantages compared to today are:

- No more manual check of the wagon sequence in the entrance group
- No more manual unclenching of couplers and removal of air hoses at the split points
- No more manual bleeding of the brakes
- No more manual decoupling on the hump

5.3.2.3.2 Variant for highly automated yards

A variant for highly automated yards allowing fully automated decoupling is provided.

These yards deal with a medium to high amount of wagons every day. Therefore, automation systems are in state-of-the-art condition. An electronic yard automation system receives the cut list via a digital interface from the RU's dispatching system. The yard automation system detects the separation of wagons on the hump, sets the points for each cut and controls the speed of wagons via retarders. Some yards have haulage systems in the classification track closing the gaps between wagons that did not touch the preceding wagon (group). Some yards even have an automatic speed control of the humping locomotive, i.e., the locomotive approaches the hump and pushes the wagon over the hump without involvement of the driver. This is done especially for optimising the time interval between the cuts. The intervals are long enough to switch the points between the wagon groups but as short as possible to reduce the occupation time of the hump by one train. Due to this feature, the yard automation system always knows the position of the locomotive. Figure 26 gives a simplified overview on the legacy functions (in green letters) of such systems.

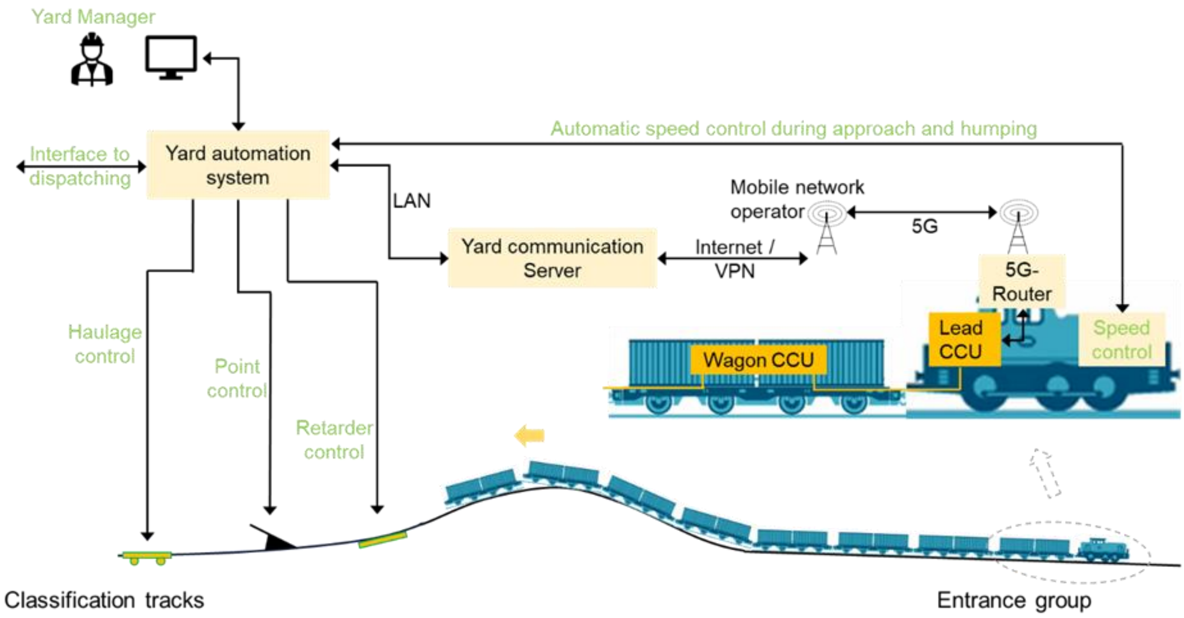


Figure 26 System architecture for highly automated yards

The design of this variant differs only on the infrastructure side. On the locomotive, the Lead CCU is also connected to a wireless network via a 5G-router. The shunting assistant with the tablet is completely replaced by software functions in the yard automation system. These take over the following tasks:

- Compare the train composition with the digitally available cut list.
- Prepare the train for hump shunting.
- Compute for each cut individually the split position, where the decoupling command shall be transmitted to the Lead CCU.
- Localise the train to determine when the split point has reached its split position.
- Transmit the decoupling commands to the Lead CCU.

This variant allows full-automatic decoupling in hump yards without involvement of staff except for the yard manager who starts the process on the control system.

5.3.2.4 Technical perspective

This section presents the components on the train and the infrastructure side, involved in the decoupling process of the introduced variants.

5.3.2.4.1 Components on the intelligent freight train (informative)

This paragraph describes the components of the intelligent freight train that are not part of this architecture. However, a summary is given for reasons of completeness and comprehensibility.

Wagon CCU

The wagon CCU is a controller deployed on each wagon. The wagon CCU uses battery power from the wagon, reads sensor information, controls actuators and communicates with other CCUs on the train network. Actuators on the wagons are amongst others, the actuators for decoupling in both DACs, the parking brake and the valves in the C-hose for disabling the brakes. The wagon CCU has a memory containing static information about the wagon. For this use case, the UIC wagon number, the length of the wagon, the number of axles and the distribution of axles over the wagon length are the relevant parameters of the data set. In exchange with other CCUs in train network, the wagon CCU contributes to the train composition detection, revealing the sequence of all wagons in the consist, and train integrity monitoring in train run mode.

Lead CCU

The Lead CCU is a master controller on the locomotive that has the same functions as the wagon CCUs. In addition, it realises the superordinate train functions with the required software and by controlling all wagon CCUs. The following aspects are of particular importance for decoupling in hump yards:

- *Train composition detection*
  The Lead CCU conducts a train composition detection which can be done after network inauguration. Network inauguration takes around 5 seconds, train composition detection another 2 to 5 seconds. The total duration is thus 7 to 10 seconds. The train composition detection is done every time after rail vehicles have been added, i.e., a coupling action has taken place. It is also done after decoupling, but it can be suppressed, if commanded.
- *Logical wagon numbering*
  When a train composition detection has been executed, all units of the train composition are numbered. This logical numbering is independent from UIC wagon numbers and only valid for the time, the train composition exists in this formation. The purpose of this is to have a way of addressing specific wagons and to gain knowledge on the sequence of wagons. The numbering is clearly defined and does not change depending on operational circumstances (e.g., change of driving direction) as long as the formation does not change. The leading locomotive (with the Lead CCU) always has the number 1. All subsequent units are numbered with increasing numbers: 2, 3, 4, ... n, where n is the last wagon of the train.

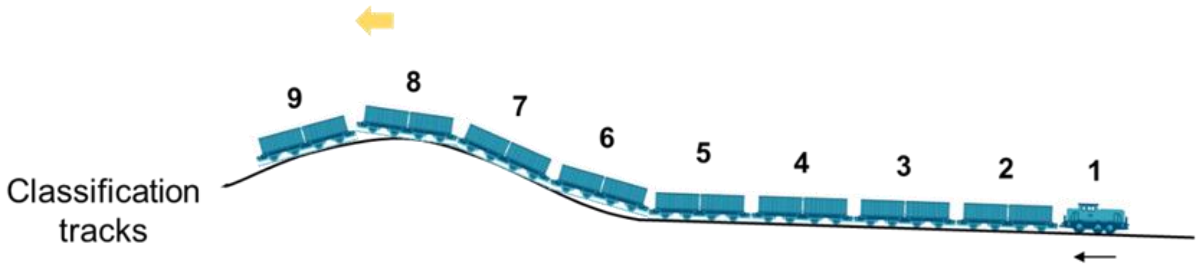


Figure 27: Example for logical numbering pattern of wagons

- *400 V/AC Powerline*
  The Lead CCU can activate and deactivate the 400 V/AC power supply for the wagons on the locomotive upon command.
- *Technical ability to decouple*
  The Lead CCU can request the state of charge of the batteries from all wagon CCUs and evaluate whether enough electric power is available to perform decoupling actions without supplementary power supply. After a comparison with a required state of charge, the Lead CCU indicates for each wagon a positive or negative result.
- *Parking brake*
  The Lead CCU can activate or deactivate the parking brake of wagons by sending respective commands to the wagon CCUs in question.
- *Decoupling*
  The Lead CCU can decouple a wagon (group) from the train by sending respective commands to the CCUs of both wagons, involved in the decoupling action at the chosen split point. The logical wagon numbering pattern is used to address the wagons. Only if both wagon CCUs have been addressed correctly, the decoupling action is executed. Afterwards, both coupler heads are in prevent recoupling state and separation of/from the decoupled wagon (group) is possible. Setting both coupler heads back into ready to couple position is done after a timer has elapsed, i.e. separation on the hump should be completed before to avoid recoupling. The timespan is variable and transmitted with the initial decoupling command to the wagon CCUs. Setting back the prevent recoupling to ready to couple is thus a local function of the wagon CCUs as one wagon CCU cannot be contacted after decoupling.
- *Disable brake*
  As option for the use case of hump shunting, the Lead CCU can command all wagon CCUs of the wagon group that shall be decoupled to disable their brakes. The brakes of the wagon that remain in the consist will not be affected. The Lead CCU will only command the decoupling action after

a conformation has been received that disabling the brakes has been accomplished. Disabling the brakes takes less than second.

- *Driver machine interface*
  In order to enable the locomotive driver to control functions of the intelligent freight train, there is a driver machine interface on the locomotive, connected to the Lead CCU.
- *External interface*
  The Lead CCU has a wired interface to applications of yard automation, described in this architecture, allowing remote control of train functions in yards. The interface has to be activated by the driver via the driver machine interface. After activation, visualisation of information regarding the train is possible. To avoid parallel inputs to the Lead CCU, control of functions via the DMI is not possible then. Instead, control is enabled exclusively via the external interface. The driver can deactivate control via the interface anytime. The interface is designed according to a request / answer principle. Applications of yard automation send a request to the Lead CCU and expect an answer, either by confirming success or failure of a requested action or by providing requested information. The interface bases on Ethernet and TCP/IP as protocol. Further details regarding the interface can be found in section 5.3.2.7.

5.3.2.4.2 Communication network

A communication network is established to allow data exchange between the Lead CCU and components on the infrastructure side. As Figure 25 and Figure 26 reveal, the network consists of several elements:

- A wired Ethernet connection between the Lead CCU and a 5G-Router, located on the locomotive,
- A wireless 5G connection between the antenna of the 5G-Router and a cell tower of a mobile network provider,
- A connection between the cell tower and a yard communication server through the internet,
- Optionally, a wired Ethernet connection between the yard automation system and the yard communication server or
- Optionally, a wireless 5G connection between a mobile device and a cell tower of a mobile network provider.

The data exchange is based on the IP-Protocol which makes communication independent from a specific physical layer. When the state-of-the-art changes in the future, e.g., 6G as next generation of mobile communication, elements of this communication architecture can be exchanged without modifying telegrams or the protocol. The suggested architecture therefore represents the favoured approach by the time this documentation is written.

5G

The 5G-technology as medium for wireless communication has been chosen due to its very low latency and expected broad availability in Europe by the time the DAC type 5 rollout will start.

Virtual private network

Obviously, some elements of the network are also part of public networks which can cause IT-Security threats to the network. Therefore, all external communication partners are part of a virtual private network, ensuring that only authenticated communication partners that have been verified are communicating with each other. Moreover, data traffic in public networks is encrypted and not readable by third parties. VPN networks are a well-known approach to connect external clients such as the locomotive or a mobile device to a closed network in a secure way.

Yard Communication Server

The yard communication server can be located on the yard site, or in case of several yards at a central location in the country. In the last case, the yard automation system also has to connect to the server via VPN. The yard communication server has several functions:

- It contains the VPN-Server functionality, accessible from the public internet. Clients like the 5G-Router or the mobile device can log in to the virtual private network if correct login data and certificates are provided.
- A dynamic name server within the virtual private network allows identification and addressing of the communication partners within the network regardless of their given IP-address.
- A user rights management software covers authorisation of users. This ensures that specific users (e.g. a shunting assistant) can only communicate with the specific partners (e.g. locomotives from a specific railway undertaking). Furthermore, user right management ensures that only one user communicates with a specific locomotive at a time. This implies that all communication is directed via the communication server.

5G-Router

The 5G-Router is the end point of the virtual private network on the locomotive side. It fulfils the following functions:

- Enable on-train communication between the Lead CCU and further components such as the ASO that may also be connected to the 5G-Router.

- Enable wireless connectivity by transferring between 5G and wired Ethernet on a physical layer. A SIM-card is required for connectivity to a mobile network operator.
- Access to the virtual private network is done via a VPN client with the required login data and certificates. Hence, functional components such as the Lead CCU do not have to consider software and configuration data for access.
- A port forwarding is configured to forward telegrams to the associated components on the locomotive such as Lead CCU or ASO.

5.3.2.4.3 Yard automation system

This paragraph describes the role of the yard automation system for control of the decoupling process. The entire scope of legacy systems will not be described. A brief introduction is given in section 5.3.2.3.2.

In order to perform the required tasks, three functional software blocks are added to the system. As the system architecture varies from supplier to supplier, the integration into the legacy systems is done supplier and yard specific.

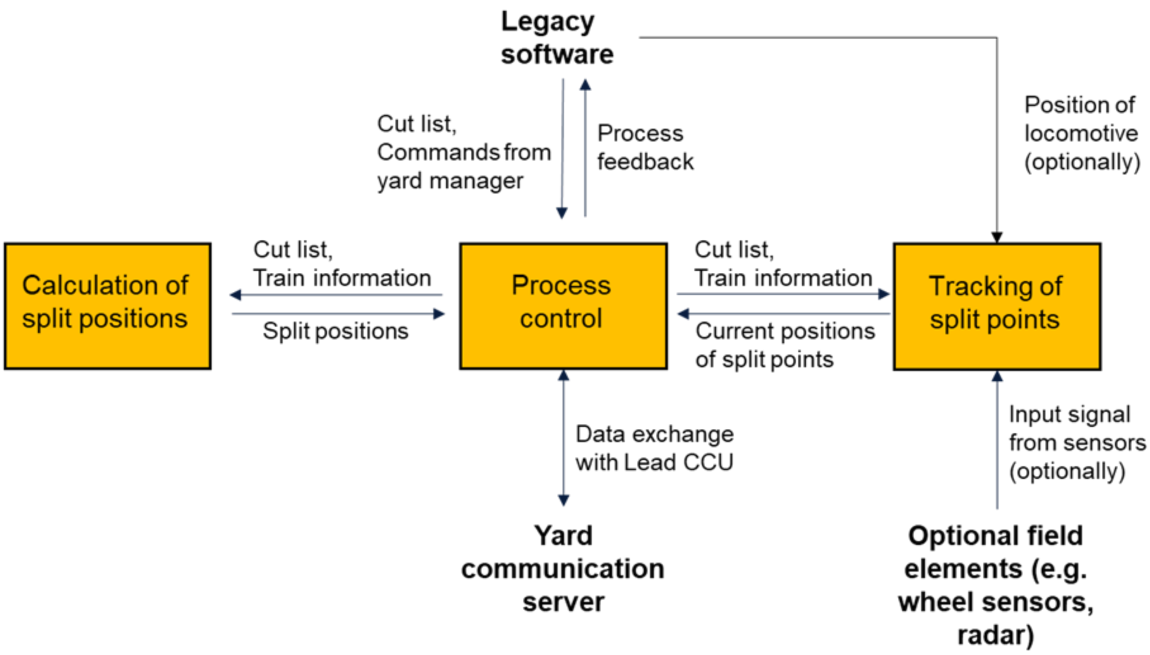


Figure 28: Functional software blocks in yard automation system

1. **Process control**
    a. Upon command from the yard manager, the cut list for an inbound train is retrieved.
    b. A communication session with the respective Lead CCU is established.

c. Preparatory checks are executed.
d. The calculation of split positions is ordered.
e. The train is reported ready to be shunted to the yard manager.
f. Upon the start command for hump shunting, the positions of all split points are tracked and decoupling commands to the Lead CCU are sent when a split point reaches its split position.
g. The communication session with the Lead CCU is closed.

2. Calculation of split positions

A simulation of the hump shunting process is executed. Based on indicated weights, split points in the cut list, requested wagon lengths, axle distribution from the Lead CCU and further parameters, the split positions, where the decoupling command shall be sent, are calculated. A digital model of the yard including track lengths and gradients is required. See Section 5.3.2.5.8 for more details.

3. Tracking of split points

During hump shunting, the current positions of all split points are tracked. A reference position is used to deduce on the location of all split points rather than a direct physical tracking. Depending on the equipment of the yard, two options that can also be combined are foreseen in this architecture.

a. Position of remote-controlled locomotive

In marshalling yards, where the locomotive, pushing the wagons over the hump, is automatically remote-controlled, the yard automation system has knowledge on the position of the locomotive. The legacy components on the locomotive report position and speed cyclically to the yard automation system. The position of a specific split point is calculated by adding the wagon lengths to the position of the locomotive.

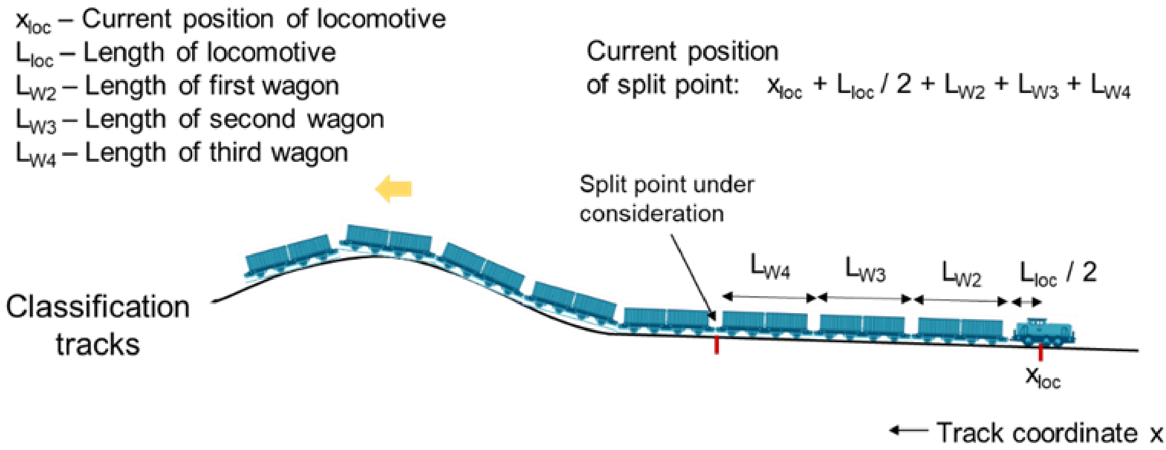


Figure 29: Tracking of position with remote controlled locomotive

b. *Sensors on the hump*
   In other yards, sensors on the hump discovering the front of the train (in driving direction) are used. Several double wheel sensors count the axles of the approaching train (including speed and direction). With the knowledge on the distribution of axles over the train length, the split points can be calculated at discrete times. In order to achieve a continuous tracking, a radar can be used for speed surveillance until the next axle is detected at any of the wheel sensors. Similar approaches are common practice in other areas of the hump. Hence, components and evaluation logic are state-of-the-art.

5.3.2.4.4 Tablet

The tablet is only used in the variant for yards with a low degree of automation. A VPN client with personalised certificates and login data is required to establish a secure connection to the communication network. An application on the tablet is used to visualise process steps and offer remote control options to the shunting assistant. The scope of the app comprises at least the following features:

- Selection of traction unit
- Visualise the train composition
- Manual preselection of split points
- Prepare hump shunting
- Trigger decoupling commands according to preselected sequence of split points

A more detailed functional overview is given in section 5.3.1.1.5. Implementation and visualisation are realised in supplier specific manner incorporating operators' wishes.

5.3.2.4.5 Personnel

This paragraph introduces human actors and their involvement in the process.

Yard manager

The yard manager is the responsible person operating the yard automation system. Typically, the yard manager sits in a control tower on the yard with visibility both on the operating system and the hump.

The yard manager commands automated processes which are the preparation and start of hump shunting.

Shunting assistant

The shunting assistant is a person that was formerly standing on the hump and throwing out the screw coupler while the couplers were still under compressive forces. The role changes in this architecture as physical work is no longer required and presence on the hump is possible but not mandatory. Only a visibility onto the hump is required.

The shunting assistant remote controls decoupling on the hump via the tablet app. He or she takes over tasks that are automatised in the variant for hump yards with a high degree of automation. These are:

- Select the locomotive pushing the wagons over the hump,
- Preselect the split points according to a cut list provided in paper form,
- Determine the split positions visually and command decoupling manually.

5.3.2.5 Functional perspective

This section focuses on the functions that have to be implemented in both variants. The following table lists the main functions and indicates how both variants realise them. The subsequent paragraphs describe the functions in detail.

Table 13: Realisation of functions by actor/system

Functions realised by actor/component	Variant for low automated yards	Variant for highly automated yards
Provide cut list	Printer	Yard automation system
Check train composition	Shunting assistant	Yard automation system
Preselect split points	Shunting assistant / tablet app	
Check ability of wagons to	Tablet app	Yard automation system

decouple		
Deactivate parking brake	Shunting assistant / tablet app	Yard automation system
Switch off 400 V/AS power supply	Shunting assistant / tablet app	Yard automation system
Provide route information		Yard automation system
Calculate/estimate split positions	Shunting assistant	Yard automation system
Choose timespan to deactivate prevent recoupling	Shunting assistant	Yard automation system
Tracking of split points	Shunting assistant	Yard automation system
Trigger decoupling commands	Shunting assistant / tablet app	Yard automation system

5.3.2.5.1 Provide cut list

It is expected that the cut list contains at least the following information:

- Sequence of wagons
- UIC wagon number for each wagon
- Total weight of each wagon
- Split points, where wagons are decoupled from the train composition for sorting

In the variant with a low degree of automation, the shunting assistant will get the cut list from a printer. In the variant with a high degree of automation, the cut list originally comes from a dispatching system in digital form. When hump shunting is prepared, the cut list is already loaded by the yard automation system.

5.3.2.5.2 Check train composition

The train composition is requested from the Lead CCU. Before hump shunting starts, a double check is done to ensure that cut list and train composition match. It shall be checked that:

- the number of wagons in the cut list equals the train composition,
- the UIC numbers of contained wagons match,
- and the sequence of wagons is the same.

In the variant for yards with a high degree of automation, the check is done by software of the yard automation system. In the variant for yards with a low degree of automation, the requested train composition is displayed on the tablet. The shunting assistant compares it with the cut list in paper form.

If a mismatch is detected, the cut list needs to be modified. That can be done by the shunting assistant, or the yard automation system informs the yard manager who can then modify the cut list in the dispatching system.

5.3.2.5.3 Preselect split points

The shunting assistant preselects all split points virtually according to the cut list. This is done while the train is standing in the entrance group as preparation for hump shunting. A later selection while the train is already on the hump distracts the shunting assistants' attention from the actual decoupling and is also a risk for the quality of operation as wrong split points might be selected in a hurry. Corrections are possible.

5.3.2.5.4 Check ability of wagons to decouple

The train composition, retrieved from the Lead CCU, contains information on the ability of wagons to decouple. When the state of charge of a battery on the wagon is too low, decoupling on either end of the wagon is not possible. All split points, indicated by the cut list, are checked. If at least one of the adjacent wagons for a given split point is unable to decouple, hump shunting cannot be executed as planned. The yard manager or the shunting assistant has to decide on possible options, e.g., charge the batteries, modify the split points or split the train in two parts by manual decoupling at the coupler heads and do the hump shunting separately with the two parts.

The check is implemented in the software of the yard automation system and the tablet app. In case of a negative result, a notification is presented to the yard manager or the shunting assistant, respectively.

5.3.2.5.5 Deactivate parking brake

The train composition, retrieved from the Lead CCU, contains information on which wagons are equipped with a parking brake and if so, whether the parking brake is active. If parking brakes are present and active, the yard automation system or the shunting assistant deactivates all parking brakes in question.

5.3.2.5.6 Deactivate 400 V/AC power supply

The train composition, retrieved from the Lead CCU, contains information on the state of the 400 V/AC power line. If activated, the yard automation system or the shunting assistant deactivate the power supply.

5.3.2.5.7 Provide route information

Most marshalling yards have two tracks leading over hump allowing a seamless transition from one train to another train that shall be sorted. Depending on the track layout both hump tracks can be reached from some or all entrance tracks. Hence, the hump track and the route to it is ambiguous and needs to be known. Route information is required to compose an individual track model for the shunting movement out of the entire digital track model of the yard. Due to curves and points, track gradients and track length vary.

The legacy software of the yard automation system needs to indicate the route, latest shortly before the approach to the hump starts.

5.3.2.5.8 Calculate / estimate split positions

The aim of the function is to determine the split positions. A split position is defined as track coordinate where the yard automation system or the shunting assistant shall trigger the decoupling command when reached by the corresponding split point (the plane defined by the two coupler front plates). In case of the shunting assistant, the split positions are determined visually with the existing professional experience. Nowadays, he or she conducts the same task with the screw coupler. Therefore, this paragraph concentrates on the yard automation system where the split positions are calculated by software. Calculation is done for all split points indicated in the cut list.

Each of those computations comprises two steps:

1. Calculation of the earliest and latest location of separation
2. Calculation of the split position

Earliest and latest location of separation

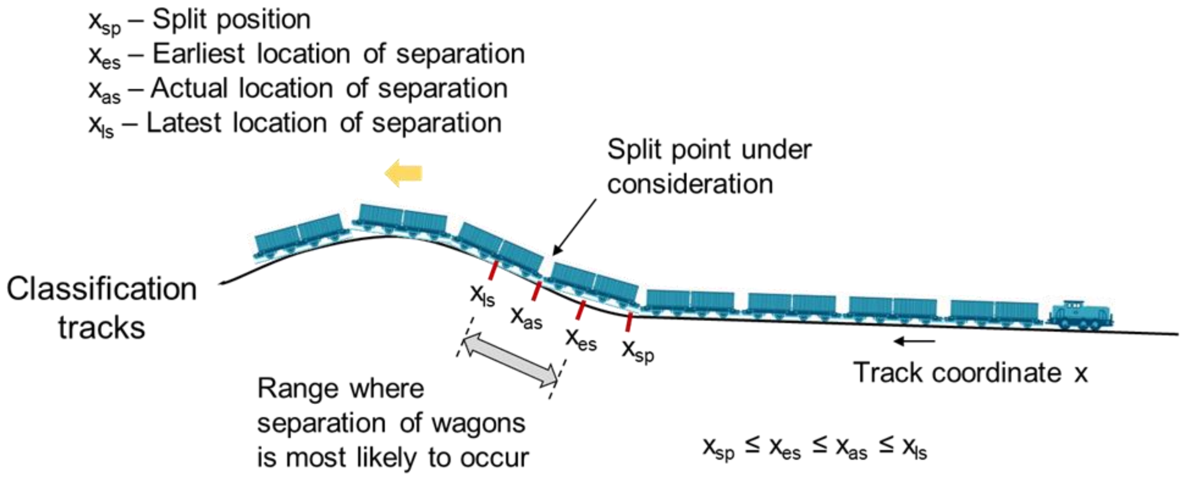


Figure 30: Locations on the hump

The actual location of separation is a track coordinate where a wagon (group), already decoupled, will separate from the rest of the train. The acceleration is caused by portions of gravity (slope forces), that pull the wagon (group) downhill. If not decoupled, both coupler heads would be charged with tension forces. This location cannot be determined beforehand because some parameters are uncertain. For these, assumptions are made. One set of parameters are best case assumptions leading to an early separation, another set of parameters are worst case assumptions leading to a late separation. Consequently, two locations are calculated, called earliest and latest location of separation. The actual separation from the train will happen between both locations.

Parameters defining the earliest and latest location of separation are listed in the table below.

Table 14: Input parameters for earliest and latest location of separation

Parameter	Dependencies	Source
Sum of slope forces	Number of axles	Train composition (Lead CCU)
	Distances between axles	Train composition (Lead CCU)
	Axle weights	Total mass of wagon (Cut list) and number of axles per wagon (Train Composition)
	Gradient profile	Digital track topology

		model and route information (both Yard automation system)
	Split points	Cut list
Resistance forces	Bogie type, axles suspension, friction on wheel-rail contact	Uncertain, best and worst case assumptions
Wind forces	Wind speed, wind direction, geometrical profile of wagons	Uncertain, best and worst case assumptions

The slope force of one axle depends on the track gradient and the axle weight. The axle weight can be obtained by dividing the total mass of the wagon by the number of its axles assuming constant load distribution. For the track gradient, a one-dimensional track model is composed. It contains track coordinates that represent the length of track sections and values for the track gradient at each coordinate. The composition of track sections is done according to the provided route information.

According to the same procedure, slope forces of adjacent axles are computed under consideration of the distances between them. Positive slope forces act with the track coordinate (towards the classification track), negative slope forces act against it (towards the entrance group). At the end, all slope forces belonging to axles of a wagon (group) that shall be decoupled are summed up.

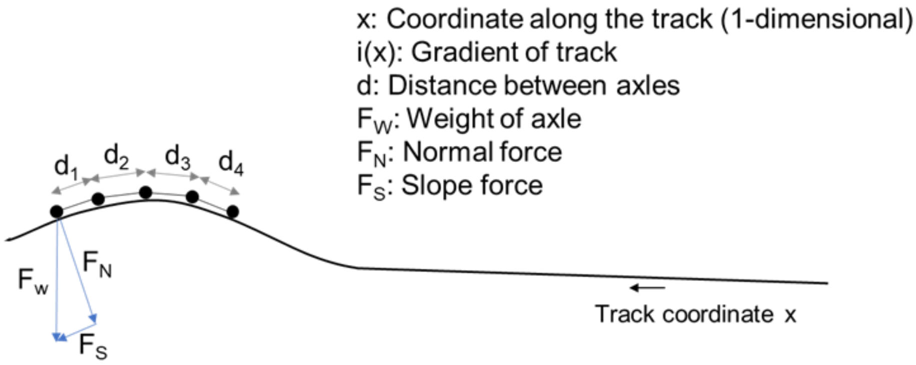


Figure 31: Slope forces

Resistance forces always act against the moving direction or track coordinate, i.e., they have a negative sign. Their absolute value is unknown. Statistically best and worst case values are assumed for calculating the earliest and latest location of separation, respectively. Suppliers for yard automation systems collected such values for specific wagon types by measurements.

Wind forces can act with or against the track coordinate, depending on the wind direction. Their absolute value depends also on the wind speed and the geometrical profile of the wagons. On highly automated marshalling yard, wind measurement devices are installed at several locations. Sensor data deliver wind speed and direction. With simplified models, assumptions for the wind forces are made.

Slope, resistance and wind forces are summed up. A simulation moving the wagon (group) over the hump reveals the track coordinate where the equilibrium of forces (sum equals zero) is reached. The simulation is repeated with best case parameters and worst case parameters to obtain the earliest and latest location of separation.

Split position

When the split point passes the earliest location of separation, the decoupling action must be finished at the latest. Otherwise, there is a risk that the coupler heads will experience tensile forces, a condition under which decoupling is not recommended (see section 5.3.2.2). The yard automation system triggers the decoupling command earlier due to delays that have to be considered. In the current phase of the project, their absolute values still unknown. Specifications and tests will reveal them.

1. *Network latency*

A very small delay of a few dozen milliseconds is caused by the communication network. It is the timespan from the moment the controller of the yard automation system sends the decoupling command until it arrives at the Lead CCU.

2. *Time required to deactivate the brakes*

Before the Lead CCU commands both wagon CCUs in question to decouple, it commands all wagons that shall leave the train composition to deactivate their brakes. The expected value is less than a second.

3. *Time required by actuators to open the coupler heads.*

When the brakes have been deactivated, the Lead CCU commands the wagon CCUs to decouple. It takes a few seconds until the actuators have driven their locking mechanisms into an unlocked position.

4. *Uncertainty margin*

It is reasonable to add an uncertainty parameter that causes the coupler heads to be decoupled before the split point reaches the earliest location of separation. There is only a negative impact on the decoupling quality by decoupling too late but no impact by decoupling earlier. Depending on the calculative accuracy of earliest location of separation, the value should be smaller or larger.

All delays are summed up. The travelled distance during this time span is calculated considering a known constant humping speed or varying speed profile calculated by the yard automation system. The travelled distance is subtracted from the earliest location of separation to obtain the split position. The procedure is repeated for all split points or earliest locations of separation respectively.

5.3.2.5.9 Choose timespan to deactivate prevent recoupling

The timespan to deactivate prevent recoupling is transmitted together with the decoupling command and needs to be sufficiently large to cover the travel duration from the split point to the actual location of separation. The timespan can be chosen to be much longer: up to standstill of the wagon (group) in the classification track where automatic coupling is desired.

In the variant for highly automated yards, the travel time between the split position and the latest location of separation is calculated considering the distance between both locations and a known constant humping speed or varying speed profile calculated by the yard automation system. An additional uncertainty margin, that needs to be determined in tests, is added to compensate for possible inaccuracies in calculating the latest location of separation and deviations of actual speeds from planned humping speeds.

In the variant for lowly automated yards, the shunting assistant chooses a default value for all split points in the tablet app. It is assumed that the shunting assistant will decouple significantly earlier than the yard automation system would do. In lowly automated yards, the humping speeds are also much lower (magnitude of 0.8 m/s). Hence, a relatively large time span needs to be chosen. There is a timespan that will suit to all split points and the operation in a specific yard. Such a value could be in the range of 60 to 90 seconds.

5.3.2.5.10 Tracking of split points

When the train starts moving and approaches the hump, the positions of all split points need to be tracked. In the variant for highly automated yards, either the position reports of the locomotive can be used, or sensors located at the hump allow detection of the train front end. Refer to section 5.3.2.5.3 for more details. In the variant for lowly automated yards, the shunting assistant follows the current position of the split point visually by watching the hump.

5.3.2.5.11 Trigger decoupling commands

In the variant for highly automated yard, the yard automation system triggers the decoupling command when the split point reaches its split position. The command is sent via the communication network to the Lead CCU. In the variant for lowly automated yards, the shunting assistant triggers the decoupling command by pushing a button in the tablet app.

5.3.2.6 Sequence diagrams

In this section, sequence diagrams are presented giving an overview on the procedure including the described functions. Figure 33 shows the sequence of exchanged telegrams and actions for highly automated yards. Figure 32 shows the respective sequence for lowly automated yards.

The diagrams show the ordinary sequence. Failure cases that may occur, e.g. a mismatch between cut list and train composition as result of the function “check train composition”, are not covered.

The following general preconditions are valid for the shown sequences:

- The traction unit is coupled to the inbound train in the entrance group.
- The traction unit operator has enabled remote control of train functions via the external interface on the DMI.
- The 5G-Router is connected to the communication network.

For the variant for lowly automated yard, the following specific preconditions are valid:

- The tablet is connected to communication network.
- The shunting assistant has visibility on the hump.

For the variant for highly automated yard, the following specific precondition are valid:

- The yard automation system is connected to communication network.

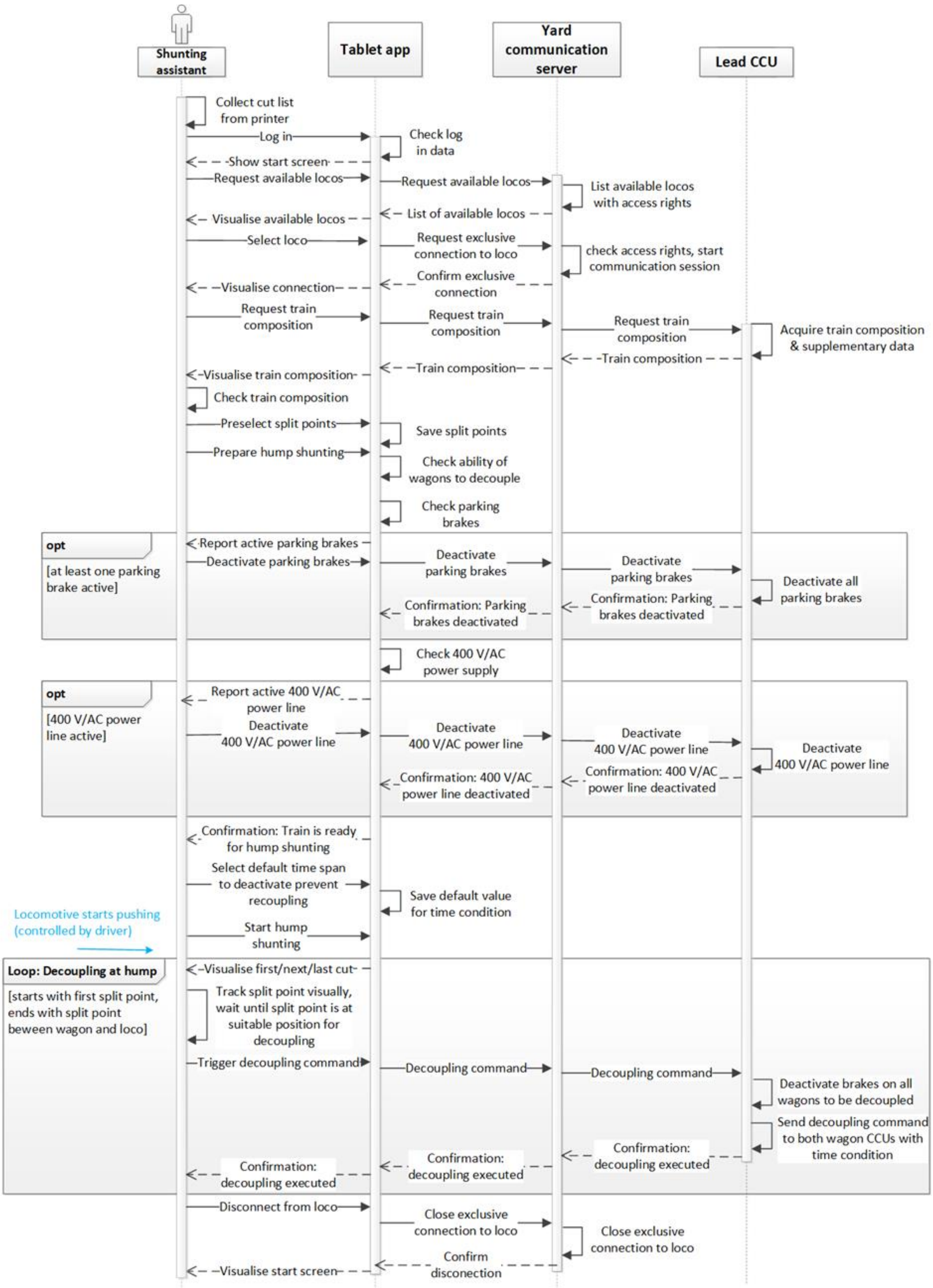
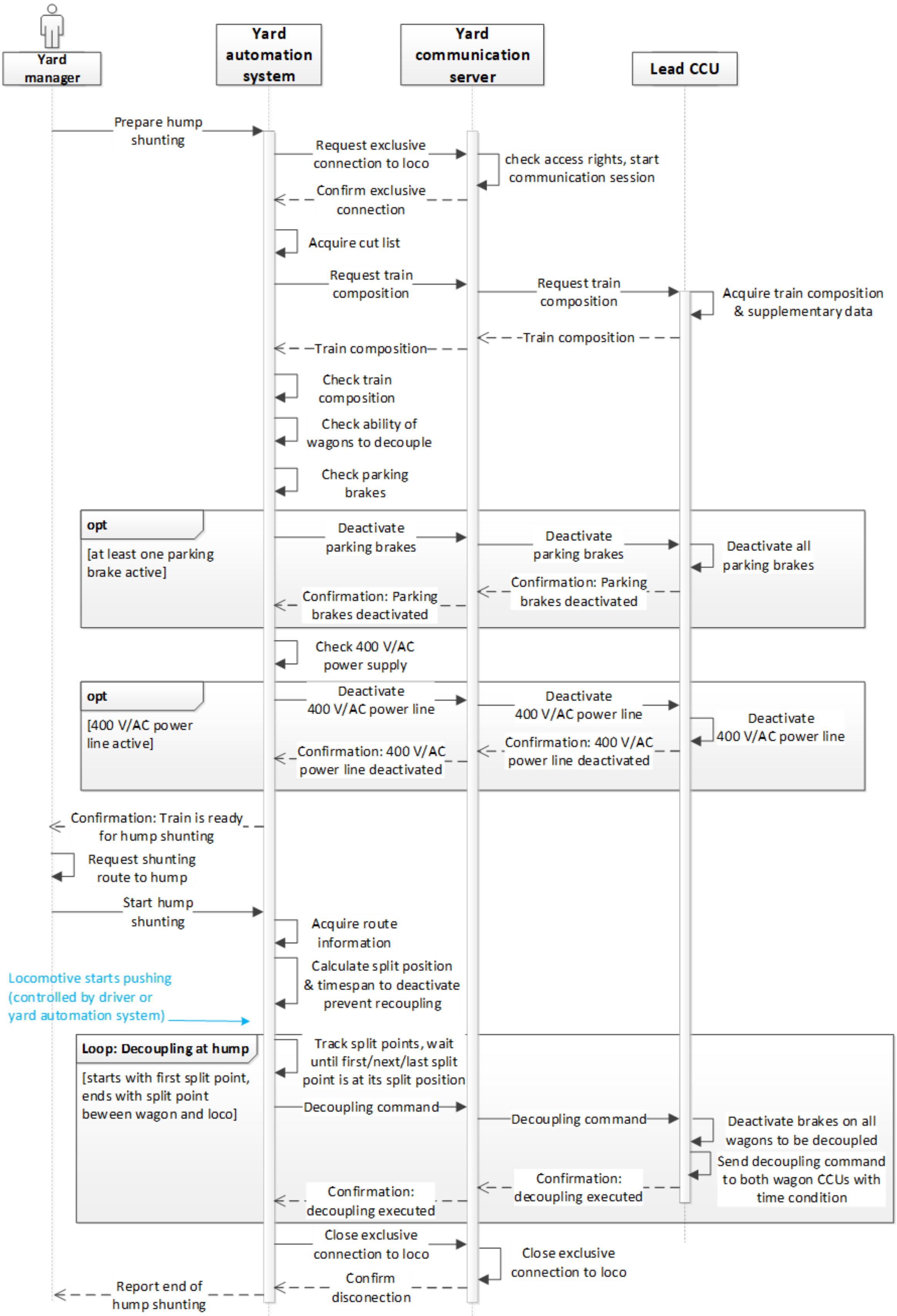


Figure 32: Sequence diagram for lowly automated yards



Yard manager
Yard automation system
Yard communication server
Lead CCU
Prepare hump shunting
Request exclusive connection to loco
check access rights, start communication session
Confirm exclusive connection
Acquire cut list
Request train composition
Request train composition
Acquire train composition & supplementary data
Train composition
Train composition
Check train composition
Check ability of wagons to decouple
Check parking brakes
opt
[at least one parking brake active]
Deactivate parking brakes
Deactivate parking brakes
Deactivate all parking brakes
Confirmation: Parking brakes deactivated
Confirmation: Parking brakes deactivated
Check 400 V/AC power supply
opt
[400 V/AC power line active]
Deactivate 400 V/AC power line
Deactivate 400 V/AC power line
Deactivate 400 V/AC power line
Confirmation: 400 V/AC power line deactivated
Confirmation: 400 V/AC power line deactivated
Confirmation: Train is ready for hump shunting
Request shunting route to hump
Start hump shunting
Acquire route information
Calculate split position & timespan to deactivate prevent recoupling
Locomotive starts pushing (controlled by driver or yard automation system)
Loop: Decoupling at hump
[starts with first split point, ends with split point beween wagon and loco]
Track split points, wait until first/next/last split point is at its split position
Decoupling command
Decoupling command
Deactivate brakes on all wagons to be decoupled
Send decoupling command to both wagon CCUs with time condition
Confirmation: decoupling executed
Confirmation: decoupling executed
Close exclusive connection to loco
Close exclusive connection to loco
Confirm disconection
Report end of hump shunting

Figure 33: Sequence diagram for highly automated yards

5.3.2.7 Telegrams

Telegrams, exchanged via the communication network, use the Transmission Control Protocol (TCP) and are noted in JSON-format. The exact layout of telegrams in JSON still needs to be defined. However, this section introduces telegram types with contained parameters.

5.3.2.7.1 Request train composition

Sender: Yard automation system or tablet app

Receiver: Lead CCU

Table 15: Telegram structure for 'Request Train Composition'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID

Message type: Identifies message type, in this case: “ReqTComp”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

5.3.2.7.2 Train composition

Sender: Lead CCU

Receiver: Yard automation system or tablet app

Table 16: Telegram structure for 'Train Composition'

Parameter Train level	Parameter Unit level	Usage	Datatype of value [Unit]
Message type		Mandatory	String
Message ID		Mandatory	UUID
Reply		Mandatory	UUID
Total length		Mandatory	Int [mm]
Number of axles		Mandatory	Int
Number of units		Mandatory	Int
Mode		Mandatory	String
Powerline state		Mandatory	Bool
Units		Mandatory	Array
For each entry in units:			
	Logical number	Mandatory	Int
	UIC wagon number	Mandatory	Int

	Length	Mandatory	Int [mm]
	Number of axles	Mandatory	Int
	Distribution of axles over length	Mandatory	Array with Int [mm]
	Ability to decouple	Mandatory	Bool
	Parking brake	Mandatory	Bool
	State of parking brake	Conditionally	Bool
	Pneumatic brake function	Mandatory	Bool

Message type: Identifies message type, in this case: "TComp".

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram "ReqTComp".

Total length: Contains total length of train in millimetres from end of coupler head to end of coupler head.

Number of axles: Number of axles for entire train.

Number of units: Total number of units in train composition (incl. loco).

Mode: Contains mode of train: "Shunting" or "Train run".

Powerline state: Value is true if 400 V/AC powerline is switched on.

Units: Array of objects, Length of array equals *Number of units*.

Logical number: Logical number of unit in train composition, refer to Figure 27.

UIC wagon number: UIC wagon number consisting of twelve digits.

Length: Length of unit in millimetres from end of coupler head to end of coupler head.

Number of axles: Number of axles of unit

Distribution of axles over length: Array containing distances of each axle from the end of one coupler head in millimetres, array length equals *Number of Axles*.

Ability to decouple: Value is true if battery level allows at least two decoupling actions.

Parking brake: Value is true if wagon has a parking brake.

State of parking brake: Parameter only exists, if value of *Parking brake* is true. Value is true if parking brake of unit is active.

Pneumatic brake function: Value is true if brake function is enabled.

5.3.2.7.3 Request decoupling

Sender: Yard automation system or YAMSmobile

Receiver: Lead CCU

Table 17: Telegram structure for 'Request Decoupling'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Split point	Mandatory	Int
Suppress train composition detection after decoupling	Mandatory	Bool
Disable brakes of wagon (group) to be decoupled	Mandatory	Bool
Condition type for setting coupler heads in 'ready-to-couple' state	Mandatory	String
Time condition	Conditionally (only if Condition type equals 'Time')	Int [s]

Message type: Identifies message type, in this case: "ReqDec".

Message ID: Identifier of message, noted as Universally Unique Identifier.

Split point: Logical number of first wagon that shall be decoupled from the train composition.

Suppress train composition detection after decoupling: Value is true if Lead CCU shall suppress a train composition detection after execution of decoupling action.

Disable brakes of wagon (group) to be decoupled: Value is true, if Lead CCU shall disable the brakes of wagon (group) that shall be decoupled, before the actual decoupling action takes place.

Condition type for setting coupler heads in "ready-to-couple" state: String equals "Time" if time condition shall be applied.

Time condition: Parameter only exists if *Condition type* equals "Time". Value is a number in seconds.

5.3.2.7.4 Acknowledgment of decoupling request

Sender: Lead CCU

Receiver: Yard automation system or YAMSmobile

Table 18: Telegram structure of 'Acknowledgment of decoupling request'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Reply	Mandatory	UUID
Acknowledgment	Mandatory	Bool

Message type: Identifies message type, in this case: “AckDec”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram “ReqDec”.

Acknowledgment: Value is true if decoupling command has been executed successfully.

5.3.2.7.5 Request activation of parking brake

Sender: Yard automation system or YAMSmobile

Receiver: Lead CCU

Table 19: Telegram structure for 'Request activation of parking brake'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Type	Mandatory	String
Wagons	Conditionally	Array of type int

Message type: Identifies message type, in this case: “ReqActPB”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

Type: Value equals “All” if the parking brake of all wagons that are equipped with a parking brake shall activate their parking brakes. Value equals “Specific” if the parking brake shall only be activated for given wagons.

Wagons: Parameter only exists if *Type* equals “Specific”. Array contains logical numbers of units that shall activate their parking brakes. Entries are sorted in increasing manner. The number 1 (locomotive) is forbidden.

5.3.2.7.6 Acknowledgment for activation of parking brake

Sender: Lead CCU

Receiver: Yard automation system or YAMSmobile

Table 20: Telegram structure for 'Acknowledgment for activation of parking brake'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Reply	Mandatory	UUID
Acknowledgment	Mandatory	Bool

Message type: Identifies message type, in this case: "AckActPB".

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram "ReqActPB".

Acknowledgment: Value is true if activation of requested parking brakes has been executed successfully.

5.3.2.7.7 Request deactivation of parking brake

Sender: Yard automation system or YAMSmobile

Receiver: Lead CCU

Table 21: Telegram structure for 'Request deactivation of parking brake'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Type	Mandatory	String
Wagons	Conditionally	Array of type int

Message type: Identifies message type, in this case: "ReqDeactPB".

Message ID: Identifier of message, noted as Universally Unique Identifier.

Type: Value equals "All" if the parking brake of all wagons that are equipped with a parking brake shall deactivate their parking brakes. Value equals "Specific" if the parking brake shall only be deactivated for given wagons.

Wagons: Parameter only exists if *Type* equals “Specific”. Array contains logical numbers of units that shall deactivate their parking brakes. Entries are sorted in increasing manner. The number 1 (locomotive) is forbidden.

5.3.2.7.8 Acknowledgment for deactivation of parking brake

Sender: Lead CCU

Receiver: Yard automation system or YAMSmobile

Table 22: Telegram structure for 'Acknowledgment for deactivation of parking brake'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Reply	Mandatory	UUID
Acknowledgment	Mandatory	Bool

Message type: Identifies message type, in this case: “AckDeactPB”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram “ReqDeactPB”.

Acknowledgment: Value is true if deactivation of requested parking brakes has been executed successfully.

5.3.2.7.9 Request activation of power supply

Sender: Yard automation system or YAMSmobile

Receiver: Lead CCU

Table 23: Telegram structure for 'Request activation of power supply'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID

Message type: Identifies message type, in this case: “ReqActPS”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

5.3.2.7.10 Acknowledgment for activation of power supply

Sender: Lead CCU

Receiver: Yard automation system or YAMSmobile

Table 24: Telegram structure for 'Acknowledgment for activation of power supply'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Reply	Mandatory	UUID
Acknowledgment	Mandatory	Bool

Message type: Identifies message type, in this case: “AckActPS”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram “ReqActPS”.

Acknowledgment: Value is true if activation of 400 V/AC power supply has been executed successfully.

5.3.2.7.11 Request deactivation of power supply

Sender: Yard automation system or YAMSmobile

Receiver: Lead CCU

Table 25: Telegram structure for 'Request deactivation of power supply’

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID

Message type: Identifies message type, in this case: “ReqDeactPS”.

Message ID: Identifier of message, noted as Universally Unique Identifier.

5.3.2.7.12 Acknowledgment for deactivation of power supply

Sender: Lead CCU

Receiver: Yard automation system orYAMSmobile

Table 26: Telegram structure for 'Acknowledgment for deactivation of power supply'

Parameter	Usage	Unit
Message type	Mandatory	string
Message ID	Mandatory	UUID
Reply	Mandatory	UUID
Acknowledgment	Mandatory	Bool

Message type: Identifies message type, in this case: "AckDeactPS".

Message ID: Identifier of message, noted as Universally Unique Identifier.

Reply: Contains Message ID of request telegram "ReqDeactPS".

Acknowledgment: Value is true if deactivation of 400 V/AC power supply has been executed successfully.

5.3.3 Stationary parking brake

The architecture description for the stationary parking brake considers three different types of solutions, each addressing the requirements specified in section 5.4.2. The solutions vary in the way of action and may be selected according to operators' preferences. The solutions need to be regarded as interchangeable rather than compulsory:

- Beam retarder, see section 5.3.3.1.1
- Automatic wedge brake, see section 5.3.3.1.2
- A combined parking retarder with stationary brake test device, see section 5.3.3.2.

5.3.3.1.1 Beam retarder

Beam retarders are proven technology among elements for speed control of wagons in hump yards. Furthermore, they represent the most powerful equipment in terms of track brakes. Common beam retarders are hydraulically driven and controlled. They are modular in design to cover different performance spectrums. Thus, they vary in their design, single-sided and double-sided, as well as in their length as shown in Figure 34. This technology can be adapted in the function of a stationary parking brake.

Figure 34: Hydraulic beam retarder single-sided (left) and double-sided (right)

5.3.3.1.1.1 Operating principle

In the beam retarder, steel brake beams are mounted at the rail inside and rail outside on individual power units. These power units apply a controllable force to the brake beams via a force linkage, which is generated by rubber spring assemblies. When the retarder is active, the inner and outer brake beam are clamping the wheels of the wagon from both sides and are in frictional contact the wheel. Thus, a laterally brake/holding force is applied on the wagon, see Figure 35 and Figure 36.

The resulting force varies via the position of a force linkage, which compresses and decompresses the rubber spring assembly and can be adjusted by a drive linkage. The degree of compression of the spring is a measure of the magnitude of the braking/holding force applied on the wheel.

Due to the floating bearing of the brake beams, different wheel width and wheel positions are considered. Spring systems within the power units ensure that the brake beams move back in its initial position after the retarder was active.

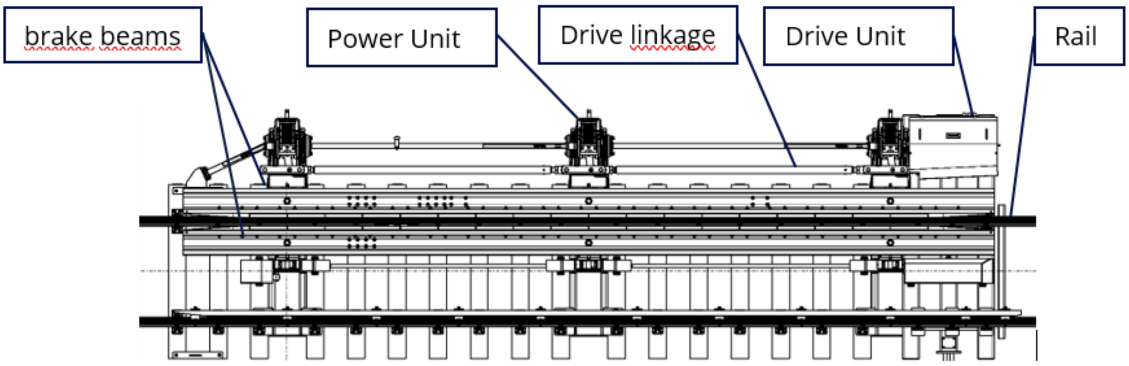


Figure 35: Beam retarder main components

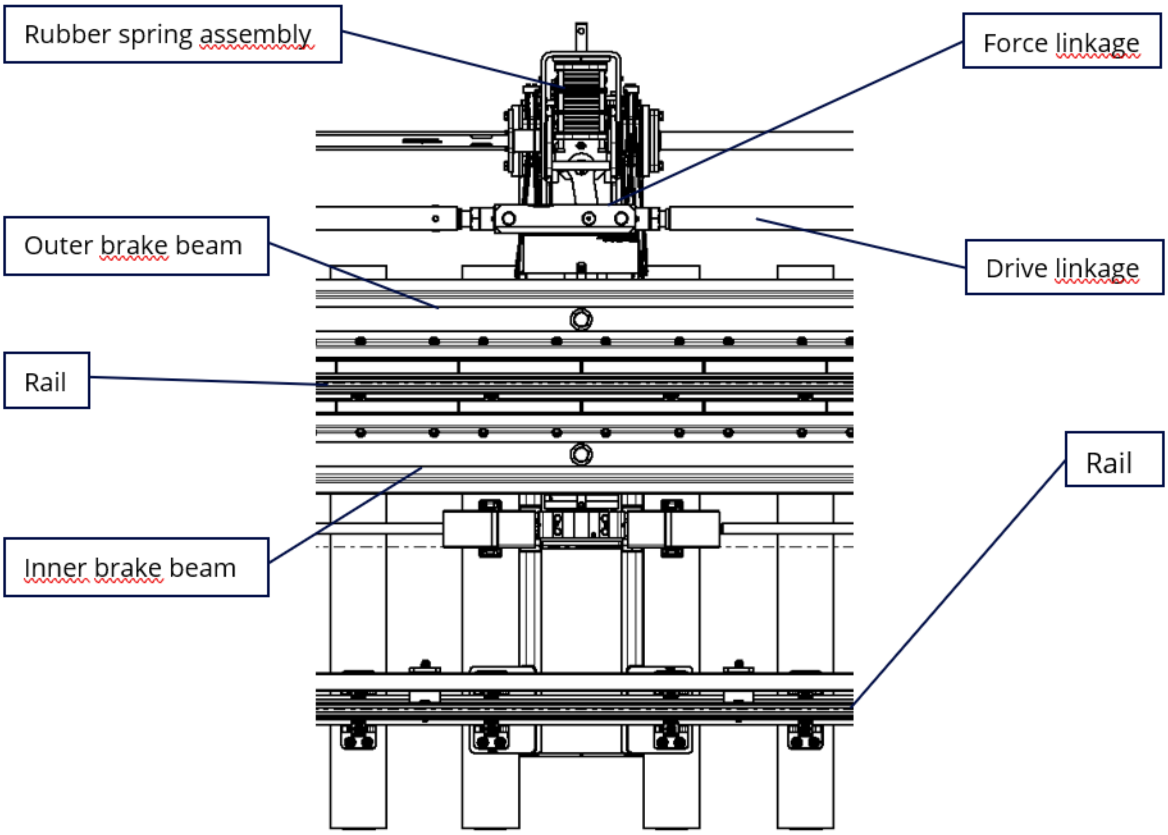


Figure 36: Beam Retarder detailed main components

Furthermore, it is possible to equip the retarder with a lifting and lowering system if it is needed. This allows the inner and outer brake beams to be lowered to ensure gauge clearance. The drive is provided by a lifting cylinder, which is located in the main drive and is passed on to each power unit via coupling linkage, see Figure 37.

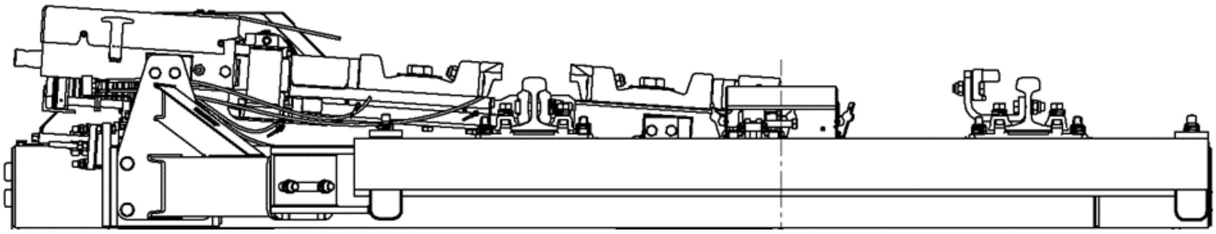


Figure 37: Lowered Beam Retarder

5.3.3.1.1.2 Dimensioning

§ 25, section 3 of DA 30.04.02:V6.0 indicates required holding forces depending on the train mass and the track gradient. For dimensioning of the beam retarder, a gradient smaller than 2,5 ‰ and a train mass of 3,000 tons assumed. A resulting holding force of approximately 150 kN is required to safely secure the wagon chain.

As described in section 5.3.3.1.1.1, the beam retarder applies the holding force lateral on each wheel. So, the applied holding force depends on the number of clamped wheels. In order to determine the number of wheels, which have to be in frictional connection with the brake beams of the retarder, the maximum applied holding force per wheel hast to be calculated.

The mathematical formula below determines the applied braking/holding force per wheel:

$$F = 2 \cdot P \cdot \mu \cdot \rho$$

- F = applied force [kN]
- P = medium clamping Force [kN]
- μ = friction factor
- ρ = roll factor

P – medium clamping force

The clamping force is generated by the rubber spring assembly. The force is limited to prevent damage to the wheels of the wagon by applying too much force.

Therefore, the maximum applied force by one rubber spring assembly is P = 170 kN.

μ – friction factor

The friction factor depends on the materials in contact, the material pairing. It can either determined in a friction test or literature values can be used. In case of the beam retarder a steel beam is in direct contact with the steel wheel of the wagon. Furthermore, it is relevant if there is a dry or lubricated contact. Following values for the friction factor are given in the literature:

- Steel/steel – lubricated surface: μ = 0.1
- Steel/steel – dry surface: μ = 0.17

In the case of the beam retarder one can assume an almost dry surface. As experience value: μ = 0.15 is assumed.

<u>ρ = roll factor</u>

The roll factor is a geometrically determined value, which mainly depends on the wheel diameter and the attack height of the brake beams on the wheel.

The smaller the attack height, the smaller the roll factor and thus, according to the formula, the smaller the braking/holding force. That is why the maximum allowed attack height should be considered. For beam retarders the maximum attack heights are 120 mm for the inner brake beam and 110 mm for the outer brake beam above rail top.

The wheel diameter of a wagon can differ between 920 mm and 1000 mm depending on the wagon type. The following parameters result depending on the wheel diameter and the mentioned attack heights:

- Wheel diameter 920 mm: ρ = 0.463
- Wheel diameter 1000 mm: ρ = 0.582

As an average value, a roll factor of ρ = 0.5 is assumed for the following calculation.

<u>F = applied braking/holding force</u>

Considering the values mentioned the following calculation results:

$$F = 2 \cdot 170\, kN \cdot 0.15 \cdot 0.5 = 25.5\, kN$$

The applied braking/holding force per wheel is 25.5 kN. Therefore, to reach a required braking/holding force of 150 kN, 6 wheels of the wagon chain have to be clamped with the beam retarder.

The performed calculation delivers an approximate value. In reality, the force distribution in the beam retarder cannot be assumed to be linear since the force effect at the power units, between the power units and at the retarder in- und outlet are different due to static over-determinism, especially when there is more than one wheel clamped by the brake beams. The force distribution can be assumed as sinusoidal curve with maximum values between the power units. Nevertheless, tests have shown, that the forces that occur are even higher than the mentioned 25.5 kN. It can therefore be assumed that the parking retarder is adequately dimensioned if the retarder applies a force on 6 wheels.

5.3.3.1.1.3 Geometry

Length of the beam retarder

To determine the required length of the beam retarder as a parking retarder, the maximum prevailing axle distance is relevant.

In general, it is known from the literature that the maximum inner axle distance is found on a 4-axle wagon. Therefore, a maximum inner axle distance of 20.5 m needs to be considered and the most unfavorable wheelset spacing in the bogie is 2 m. The maximum wheel diameter is 1 m. Refer to Figure 38.

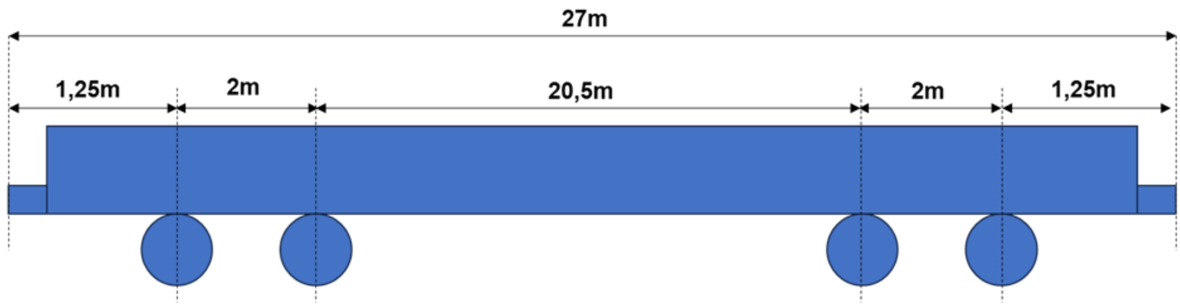


Figure 38: Axle distance and wheelset spacing

As described in section 5.3.3.1.1.2, six wheels of the wagon chain have to be clamped with the beam retarder to reach the required braking/holding force of 150 kN.

In consequence, the minimum effective brake beam length for a single-sided retarder is as follows:

Minimum effective brake beam length = 2 x 2 m (wheelset spacing) + 20,5 m (axle distance) + 2 x 1,25 m (wagon length above last wheel) + 2 x 0,5 m (wheel diameter) = 28 m

In addition to the effective brake beam length, a brake beam overhang of 1,5 m must be taken into account for the inlet and outlet. Therefore, the total length of a single-sided beam parking retarder would be approx. 31 m.

A double-sided retarder has the advantage that it is shorter in overall length since an entire axle with two wheels is always clamped. In this case, 3 axes must be clamped. In comparison, the minimum effective brake beam length for a double-sided retarder is as follows:

Minimum effective brake beam length = 2 m (wheelset spacing) + 20,5 m (axle distance) + 2 x 0,5 m (wheel diameter) = 23,5 m

Adding the overhang for the inlet and outlet, the total length of a double-sided beam paring retarder would be approx. 26,5 m.

<u>Width of the beam retarder</u>

As shown in Figure 35 and Figure 36, the power units of the beam retarder protrude beyond the sleeper gate. In case of the single-sided beam retarder, it requires approx. 2,3 m of space on one side from the center of the track. On the side where the power units are not located, the single-sided beam retarder closes with the sleepers.

A double-sided retarder therefore requires approx. 2,3 m of space from the center of the track on both sides.

<u>Gauge / clearance profile</u>

With an inner brake beam height of 120 mm and an outer brake beam height of 110 mm above the top of the rail during the active state and a brake beam height less than 80 mm above the top of the rail in the lowered or inactive state, the beam retarder complies with the requirements of the TSI or the clearance gauge according to DIN EN 15273-3: reference line GI2.

<u>Overview geometry</u>

Table 27: Overview geometry beam retarder

	Single-sided beam retarder	Double-sided beam retarder
Length	Approx. 31 m	Approx. 26,5 m
Width	Approx.2,3 m on one side from the track centre	Approx. 2,3 m on both sides from the track centre
Gauge/clearance profile	Applies to TSI / DIN EN 15273-3	Applies to TSI / DIN EN 15273-3

The dimensions, described in this section, are based on empirical values of hydraulically driven beam track brakes. The solution with an electric drive may therefore deviate slightly from these specifications.

Overall, the solution should be aimed at as a double-sided beam retarder. This has the advantage of a shorter overall length. Due to the calculated longer overall length of the single-sided retarder, two systems would probably have to be implemented in this case. This would probably not be the case with a double-sided retarder.

5.3.3.1.1.4 Drive

Common beam retarders are driven hydraulically. In order to supply the hydraulic cylinders in these beam retarders with hydraulic fluid, special peripheral equipment such as an oil tight pipe channel system and a hydraulic supply building with pump units is needed. This is to ensure following functions:

1. Sufficient supply of force
2. Fast response times
3. Insensitive to impacts during a braking process

Due to the control and operation mode of a parking brake, functions 2 and 3 do not have to be considered. Therefore, an electric drive in the form of electric lift cylinders is useful. This has the advantage that complex peripheral equipment can be dispensed with. The drive can be located at the end of the retarder and integrated in the steel frame.

For both drive technologies, an end position interlock must be taken into account. This ensures that the parking retarder does not lose its position when it is active and the power supply is switched off. For a hydraulically driven retarder an appropriate shut off-valve can be integrated. In case of an electrically driven retarder an automatic electromechanical interlock/brake integrated in the electric lift cylinders can be used.

5.3.3.1.1.5 Actuators

The beam retarder has two types of actuators that are required for activation and deactivation. An example for these actuators is illustrated by Figure 39 for a single-sided beam retarder. This specific case shows actuators that are driven hydraulically.

The lifting cylinder can move the braking beams either in lowered or in lifted position. The braking beams lie on lifting wedges which can be moved in trackwise direction via the lifting cylinder. The lowered position is required for rail vehicles to pass safely without any conflicts in the profile. The lifted position is the working position of the beam retarder. Only in lifted position, the braking beams can be moved towards or from the wheels.

This lateral movement of both the inner and outer beam is done by the second actuator, the braking cylinder. The braking cylinder can drive both beams into a position where they are fully released from the wheels and lifting or lowering is possible or into a position where the required holding force acts on the wheels.

A double-sided beam retarder has two lifting cylinders and two brake cylinders, one for each side respectively.

Figure 39: Example of actuators for a beam retarder

5.3.3.1.1.6 Sensors

Several types of sensors are used to monitor the beam retarder:

1. Sensor to detect the retarder in lowered position, one for each side of the retarder,
2. Sensor to detect the retarder in lifted position, one for each side of the retarder,
3. Two sensors allowing the controller to measure the braking level (traveling distance of brake cylinder, corresponds directly to a specific holding force), two for each side of the retarder,
4. Two double wheel sensors located at each end of the retarder, respectively.

All sensors are inductive proximity switches delivering a specific current depending on their state. The controller distinguishes between four different states that each sensor can have:

1. Sensor detects object,
2. Sensor detects no object,
3. Cable interrupted,
4. Short circuit in cable

This allows the controller not only to detect objects but also to reveal information on the integrity of measurement.

5.3.3.1.1.7 Controller

The controller is a subsystem of the beam retarder, installed in the yard tower or an outdoor cabinet. If several tracks of the entrance group are equipped with beam retarders, it will control all of them. For simplicity reasons, the description in this section only relates to one beam retarder.

The controller consists of a computer with control software but also hardware components transforming interfaces, e.g., current signals from the sensors to digital signals or digital signals to analogue signals for the actuators. Figure 40 shows functional blocks of the control system which are detailed in the following paragraphs.

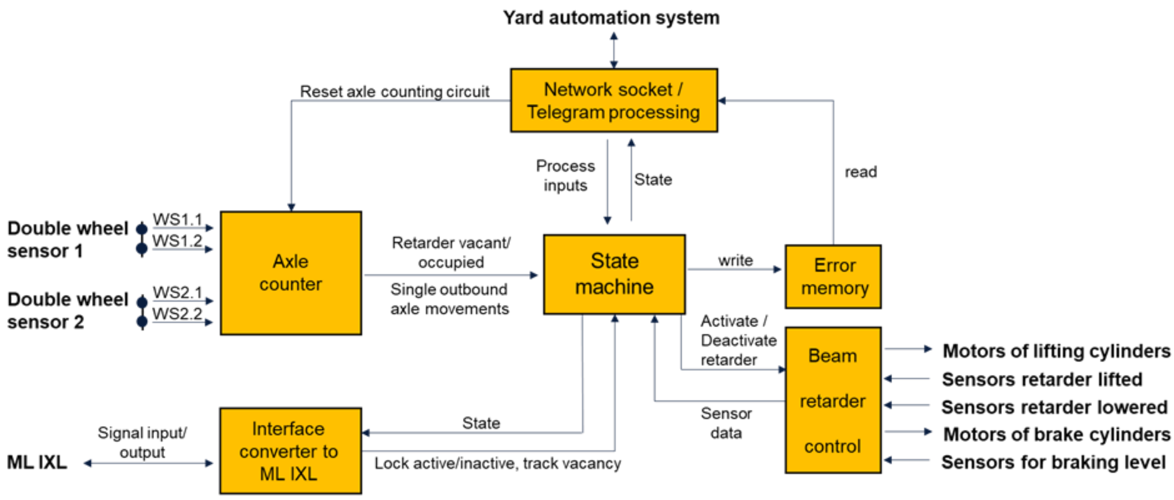


Figure 40: Control system for beam retarder

Axle counter

The current signals of the two double wheel sensors are transformed into I/O signals and evaluated by a software block. Via the sequence of axles, detected on one double wheel sensor, single axle movements into or out of the retarder are determined. Based on these events, an axle counting circuit determines the number of axles located inside the retarder. Single axle movements out of the retarder and vacancy information (retarder occupied or vacant) are transmitted to the state machine as input parameters. In rare cases, axle counting circuits miscount axles. In consequence, the track section seems to be occupied even though no axle is inside. The software block can reset the axle counting balance based on a corresponding input command.

Interface converter to ML IXL

The controller has an interface to the mainline interlocking (ML IXL) which is in charge of the entrance group. As there are different types of interlocking technologies, the interface converter has to adapt to the technology and model that is found in place. In most cases (year 2023), relay interlockings are deployed in the entrance group of European marshalling yards. To interface these interlockings, single wires giving/receiving a voltage signal are used. Suitable adaption components between voltage signals and the digital controller are required as interface converter.

The track vacancy state of the entire entrance track (occupied or vacant) is read as input and transferred to the state machine. Active train routes into or through the track from any side are interpreted as lock in inactive state and transferred to the state machine. In return, the state of the beam retarder is transmitted to the mainline interlocking. Only two states are distinguished: The inactive state indicates that the track is passable for trains. Any other state indicates that the track is not passable for trains.

Telegram processing

The controller has an interface to the hump control system which is operated by the yard manager. The yard manager organises shunting operation in the marshalling yard. Commands for controlling the functions of the beam retarder are given by the hump control system. Refer to section 5.3.3.1.1.8 for more details.

As the introduction of the beam retarder aims to achieve a high degree of automation, it is expected that the marshalling yard is equipped with state-of-the-art technology, amongst others a digital hump control system. Hence, it can be assumed that the interface relies on telegrams exchanged via a network socket.

The telegram processing block receives telegrams from the hump control system and provides the requests to other functional blocks. The telegram processing block replies to all incoming telegrams, either by confirming that the respective command has been received and will be executed or by denying the command specifying the reason for which it cannot be executed in the current state. The following incoming telegram types are foreseen:

- Activate beam retarder (input for state machine)
- Deactivate beam retarder (input for state machine)
- Activate maintenance mode with sender id (input for state machine)
- Deactivate maintenance mode with sender id (input for state machine)
- Command for fault clearance (input for state machine)
- Reset axle counting balance (input for axle counter)
- Request current state (reply to hump control system with current state of state machine)

The telegram processing block also sends telegrams to the hump control system. For this purpose, IP-address and port are configured.

The hump control system can request the current state of the beam retarder during start up, see above. However, the telegram processing block reports any change of the state (event-based) to the hump control system. In the case of the states Alarm or Failure, the respective entries from the error memory are read and included in the outgoing telegrams.

Beam retarder control

The functional block comprises hardware and software. The hardware contains the interface to sensors and actuators of the beam retarder including switch amplifiers and I/O modules for the sensors and relays for the electric motors driving the actuators.

A software blocks evaluates sensor signals to determine the required input parameters for the state machine and control of activating or deactivating procedures.

The software also includes the activation and deactivation procedures. The following steps are executed upon command from the state machine.

Table 28: Activation and deactivation procedure

Activation	Deactivation
1. Start the timer measuring the time span required for activation. 2. Start electric motors to drive both lifting cylinders in lifted positions. 3. Stop electric motors of lifting cylinders when lifted positions are reached. 4. Start electric motors to drive braking cylinders in braking position. 5. Stop electric motors of braking cylinders when configured braking level is reached. 6. Stop the timer.	1. Start the timer measuring the time span required for deactivation. 2. Check whether both braking levels are zero. If yes, skip steps 3 and 4. 3. Start electric motors to drive braking cylinders in release position. 4. Stop electric motors of braking cylinders when braking level of zero is reached. 5. Start electric motors to drive lifting cylinders in lowered position. 6. Stop electric motors of lifting cylinders when lowered position is reached. 7. Stop the timer.

The timer values are available for the state machine. The procedure is interrupted if the state machine leaves the states Activating or Deactivating before the procedures have been completed.

The required holding force needs to be configured as braking level that has to be achieved in the activation procedure.

In maintenance mode, the control of the electric motors is handed over to local operation directly at the beam retarder. The beam retarder is not controlled via this functional block in maintenance mode.

Error memory

The error memory contains entries on failures or malfunctions of the beam retarder. Each entry includes a timestamp, an error code, referring to a component, event and error type, and a flag indicating whether the entry has already been transmitted to the hump control system.

The entries are added to the memory by the state machine in the states Failure or Alarm. When the telegram processing block reports the change of state to the hump control system and requests the entries, the error memory marks them as read. By doing so that only the most recent error entries are transmitted to the hump control system relating to the current situation. Entries are deleted after 28 days in order to limit the required memory space. Entries marked as read younger than 28 days are available for investigation in case incidents should happen on the marshalling yard involving the beam retarder.

State machine

The state machine controls the state of the beam retarder depending on input parameters that are provided by the surrounding functional blocks. Figure 41 shows the diagram of the state machine. It has 7 states and 14 transitions between them. The initial state is Deactivating.

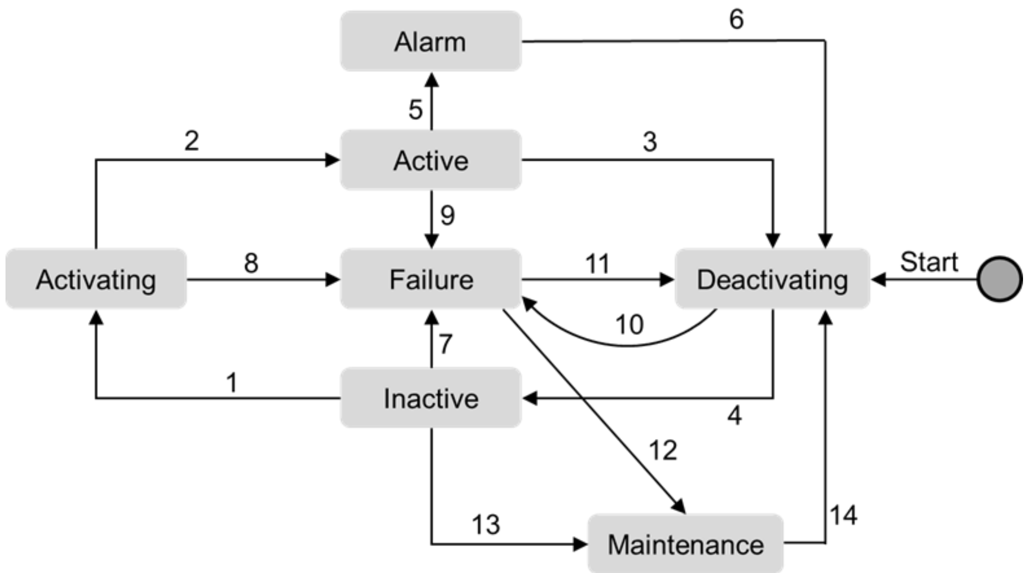


Figure 41: State machine for beam retarder control

In the following table, the states and their actions are defined:

Table 29: States and actions

State	Description	Actions
Inactive	The retarder is passable by rail vehicles without any conflicts. No holding forces are applied to rail vehicles.	-
Active	The beam retarder applies holding forces to wheels of wagons that are located within the retarder.	-
Activating	The beam retarder is in process of activation.	The procedure for activation is followed by the functional block of beam retarder control.
Deactivating	The beam retarder is in process of deactivation.	The following steps are executed: 1. If local operation is enabled, remote operation is enabled instead. 2. It is checked whether the braking levels are zero and the retarder is already lowered. In the positive case, nothing more is done. In the negative case, the procedure for deactivation is followed by the functional block of beam retarder control.
Failure	A defect of the retarder or unavailability of the interface to the ML IXL has been discovered. The actual state of the retarder is unknown and continuous safe operation is not possible. A repair is required.	The reasons that triggered the transition into Failure mode are written into the error memory.
Alarm	State of error revelation: The retarder is in active state, but it is not guaranteed that the retarder is able to prevent unintentional movement or unintentional movement has already been discovered.	The reasons that triggered the transition into Alarm mode are written into the error memory.
Maintenance	The maintenance mode allows service personnel in the track to undertake repair or maintenance work. The retarder can only be operated locally but not remotely.	The local operation of the retarder is enabled.

In the following table, transitions between the states are defined:

Table 30: Transitions

Nr.	From	To	Conditions
1	Inactive	Activating	The axle counting circuit reports the retarder to be occupied, the lock in inactive state is not activated by ML IXL and a command from the yard automation system to activate the retarder is received.
2	Activating	Active	The beam retarder is lifted and the configured braking level is reached on both sides.
3	Active	Deactivating	A command from the yard automation system is received to deactivate the retarder.
4	Deactivating	Inactive	The beam retarder is lowered and a braking level of zero is reached.
5	Active	Alarm	At least one of the following conditions are true: • A decrease in the braking level is observed. • At least one single axle movement out of the retarder by at least one of the double wheel sensors is observed.
6	Alarm	Deactivating	A command from the yard automation system is received to deactivate the retarder.
7	Inactive	Failure	At least one of the following conditions are true: • The ML IXL reports the track to be vacant but the axle counting circuit reports the retarder to be occupied. • The first double wheel sensor is disturbed. • The second double wheel sensor is disturbed. • The sensors detecting the retarder in lifted position are disturbed. • The sensors detecting the retarder in lowered position are disturbed. • The sensors allowing the controller to measure the braking level are disturbed. • The interface to the ML IXL is not available.
8	Activating	Failure	At least one of the following conditions are true: • The activation process exceeds a time period of more than 150% of the ordinarily required time for activation. • The first double wheel sensor is disturbed. • The second double wheel sensor is disturbed. • The sensors detecting the retarder in lifted position are disturbed. • The sensors detecting the retarder in lowered position are disturbed. • The sensors allowing the controller to measure the braking level are disturbed.
9	Active	Failure	At least one of the following conditions are true:

			• The first double wheel sensor is disturbed. • The second double wheel sensor is disturbed. • The sensors detecting the retarder in lifted position are disturbed. • The sensors detecting the retarder in lowered position are disturbed. • The sensors allowing the controller to measure the braking level are disturbed. • The interface to the ML IXL is not available.
10	Deactivating	Failure	At least one of the following conditions are true: • The deactivation process exceeds a time period of more than 150% of the ordinarily required time for deactivation. • The first double wheel sensor is disturbed. • The second double wheel sensor is disturbed. • The sensors detecting the retarder in lifted position are disturbed. • The sensors detecting the retarder in lowered position are disturbed. • The sensors allowing the controller to measure the braking level are disturbed.
11	Failure	Deactivating	A command for fault clearance is received from the yard automation system, all sensors (first double wheel sensor, second double wheel sensor, sensors detecting the retarder in lifted position, sensors detecting the retarder in lowered position and sensors allowing the controller to measure the braking level) and the interface to the ML IXL are serviceable.
12	Failure	Maintenance	A command for setting the retarder in maintenance mode from a post of the yard automation system is received.
13	Inactive	Maintenance	A command for setting the retarder in maintenance mode from a post of the yard automation system is received.
14	Maintenance	Deactivating	A command for deactivating the maintenance mode of the retarder is received from the same post that requested its activation.

5.3.3.1.1.8 Neighbouring systems

This section describes necessary adaptations of neighbouring system which are outside of the system **boundary** and thus not part of the architecture. However, the intention of the authors is to provide a wholistic picture of required adaptions for the introduction of the beam retarder.

<u>Yard automation system</u>

The existing yard automation system found in the marshalling yard should be modified with regard to two aspects: The operation of the beam retarder and consideration of its state in legacy processes.

The yard automation system has at least one operating system including a graphical user interface, mouse and keyboard. Typically, there are even several redundant operating systems that can used by both the yard manager and maintenance personnel. The yard manager uses the operating system to steer the shunting operation in the marshalling yards, in particular for shunting operation over the hump into the classification tracks. Maintenance personnel use the operating system for diagnosis, trouble shooting and fault clearance.

The authors recommend to integrate the beam retarder in the operating system, allowing users to see the state of the retarder in the track layout, operate it via buttons and investigate potential error messages.

In the larger European hump yards, automatic approach and humping by a remote-controlled locomotive is common. This remote-controlled operation is done by a subsystem of the hump control system. The existing checks prior to the approach should be complemented by the beam retarder making sure that shunting movements only start when the retarder is deactivated. Sending of activation commands to the controller of the beam retarder while the automatic approach is ongoing shall be prevented within the hump control system.

<u>Mainline interlocking</u>

The beam retarder is intended to prevent unintentional movements of parked wagons but does also represent an obstacle for train movements when activated. Such movements can be distinguished in train routes and shunting routes from a signalling point of view. Shunting routes are referred to as driving on sight because obstacles induced by the railway system may be on the route. In contrast to shunting routes, train routes, that are signalled to the driver, mean that the next track section is free of such obstacles. A train driver does not expect that beam retarders may be active and is not required to observe it. In the worst-case scenario, a derailment is possible.

Two cases have to be considered and prevented:

1. The retarder must not be activated as long as the train route is set.
2. The train route must not be set when the retarder is active.

Both cases are however unlikely to happen, as the activation of the retarder requires axles to be within the beam retarder, see transition 1. In the first case, the track is vacant when the train route is set. Consequently, the beam retarder cannot be occupied at the same time. In the second case, the beam retarder would be occupied but setting a train route requires a vacant track. Such scenarios are only possible if the axle counting circuit of the beam retarder erroneously reports an occupied retarder even though the entire track is vacant. In order to meet this concern and thereby introduce another layer of safety, it is inevitable to design an interface to the mainline interlocking with mechanisms that prevent an active train route into the entrance track when the beam retarder is also active at the same time.

The first case is covered by the state machine of the controller. Active train routes are read in from the interlocking, cause a lock in inactive state and prevent activation, see transition 1. The second case must be realised in the mainline interlocking.

As stated before, relay interlockings are still the most frequent type of interlocking in entrance groups. Therefore, the following description focuses on these. Other solutions need to be evaluated for other interlocking types.

A relay interlocking works according to the geographical principle. Each component in the field such as signals, points or derailers is represented by a relay group in the interlocking. The relay groups are connected with each other in the same manner as they are located in the field. A train route is searched and verified via search and echo currents that are directed through the relay groups.

The beam retarder is a new field element which is not represented by an existing type of relay group. Instead of designing a new relay group, the authors recommend using an existing type of relay group with similar properties. This relay group has to be installed and connected with the neighbouring legacy relay groups such as points or signals.

A suitable element with very similar properties is the key lock. Key locks are typically used for manual points which are part of train routes. Personnel in the field can remove the key from the lock to open a point and set the point manually towards a siding. As soon as the key is removed from the lock, a train route can no longer be set. A corresponding relay group in the interlocking prevents this. On the other side, the key cannot be removed from the lock as long as the route is active. Hence, the relay group for a key lock can prevent setting of train routes and can create electric signals when the route is active. The actual key lock can be imitated by software and hardware components of the controller for the beam retarder. Only the corresponding relay group needs to be integrated into the mainline interlocking.

5.3.3.1.2 Automatic Wedge Brake

The Automatic Wedge Brake is a recently developed device designed to prevent unintended movement of parked wagons on the track. The system incorporates a minimum of one bogie, moving on a distinct track located between the rails, which is specifically intended to block a single wheel of a wagon. The modular design allows for the use of multiple bogies on the same track, securing several wheels simultaneously. Once activated, the system moves automatically to the axle of the wagon, securing the wheel. The drive system operates electrically.

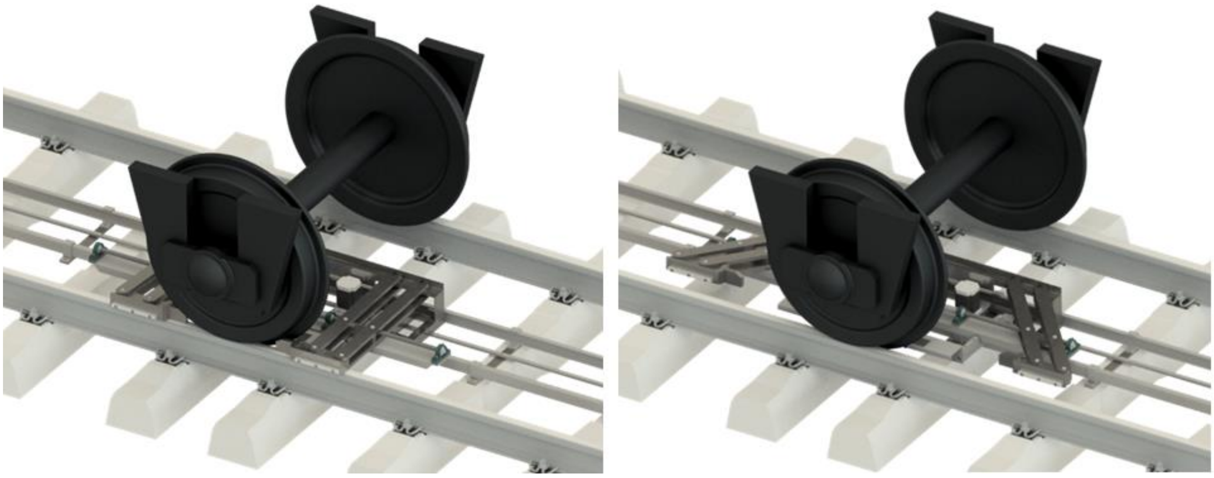


Figure 42: Wedge brake (left: activated, right: deactivated)

5.3.3.1.2.1 Operating principle

In a securing scenario, the bogie initially resides in its parking position at the start of the track. Once the train enters and the wagons to be secured are in place, the wedge brake is activated. The bogie then moves along the track and identifies the wheels using its sensors. Following positioning, the wedge mechanism activates and fine positioning of the bogie occurs as the mechanism closes. The front and back wedges are placed on the wheel and a controllable clamping force is applied to prevent unintentional movement of the wagon. The maximum force depends on the wheel contact force resulting from the weight of the wagon. For maintaining the same force during power outages, a worm gear drives the wedge mechanism.

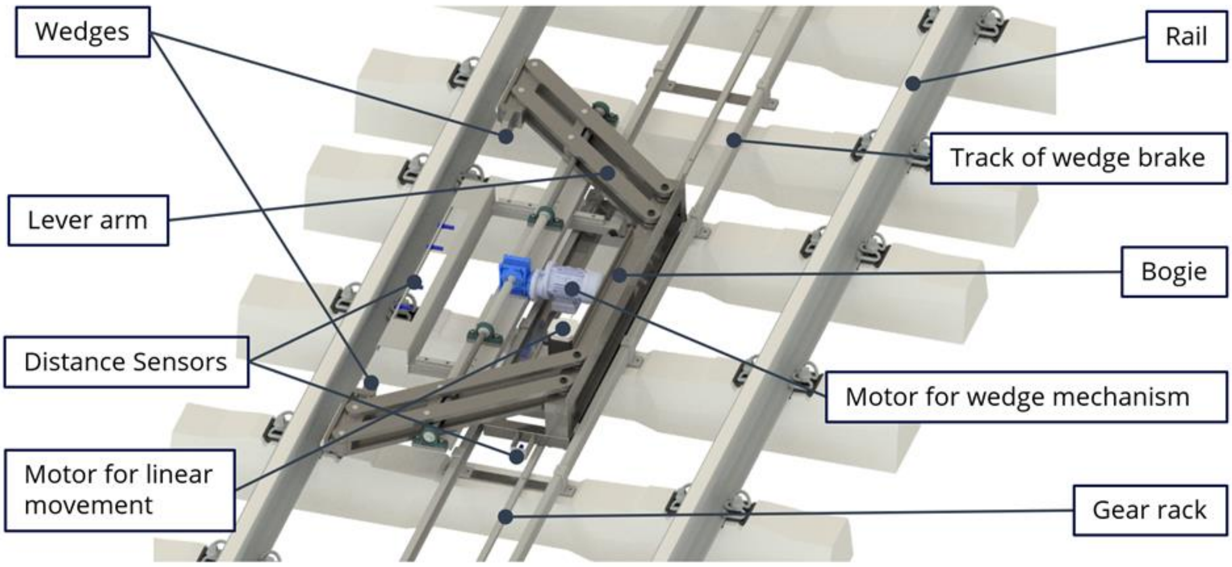


Figure 43: Wedge brake main components

5.3.3.1.2.2 Dimensioning

The wedge brake exerts a radial clamping force on the front and rear sides of the wheel. The magnitude of the brake force is determined by the wheel contact force, as well as the static friction coefficients between the rail and wheel, and between the wedge and wheel/rail. All contact surfaces are constructed from steel, and thus the literature stipulates the following factors for static friction.

- Steel/steel – lubricated surface: $\mu = 0{,}1$
- Steel/steel – dry surface: $\mu = 0{,}5 - 0{,}8$

For calculation a static friction coefficient of $\mu = 0{,}15$ is used.

The Wedge Brake blocks one wheel, thus preventing its rotation. Due to the connection throughout the axle, both wheels are immobilized. To determine the brake force of one bogie, it is essential to ascertain the wheel contact force.

$$F_B = 2 * F_W * \mu$$

- F_B ... Brake force
- F_W ... Wheel contact force
- μ ... Static friction coefficient
- $Factor$ 2 ... Two wheels are blocked.

With a wheel contact force of $100kN$:

$$30kN = 2 * 100kN * 0{,}15$$

Achieving a brake force of $30kN$ with one bogie and a wheel contact force of $100kN$ is feasible. Nonetheless, a minimum of five bogies is required to achieve a brake force of $150kN$.

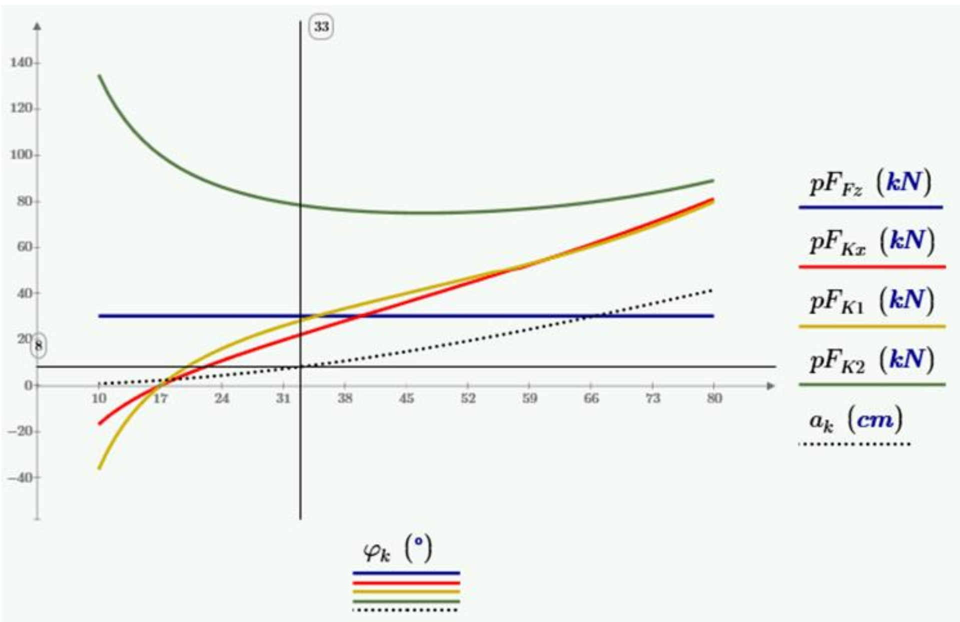


Figure 44: Forces depending on wedge height

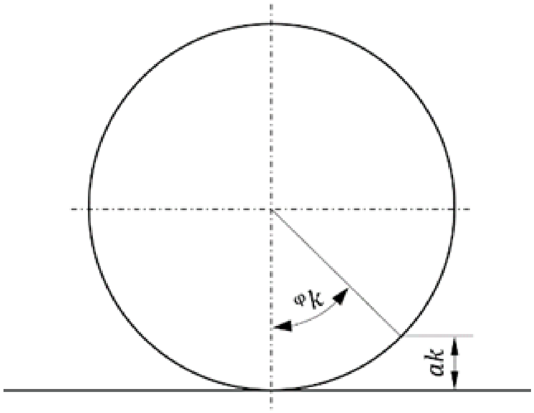


Figure 45: Correlation between φ_k and a_k

Figure 45 shows the correlation between the wheel-angle φ_k and the wedge height a_k.

Figure 44 shows following forces:

- pF_{Fz}... Break force.
- pF_{Kx}... Force that is needed to clamp the wedges together.
- pF_{K1}... Radial wheel force on wedge 1
- pF_{K2}... Radial wheel force on wedge 2
- a_k... wedge height

Figure 44 demonstrates that the breaking force remains constant over the height of the wedges and is not influenced by the wedge's height. The force between the wedges, however, increases with height, making a lower wedge preferable for a lower clamping force.

Two scenarios limit the height of the wedge: First, the height of the UIC 505 Profile dictates that the wedge must be lower. Second, the minimum wedge height must ensure that over-rolling is impossible.

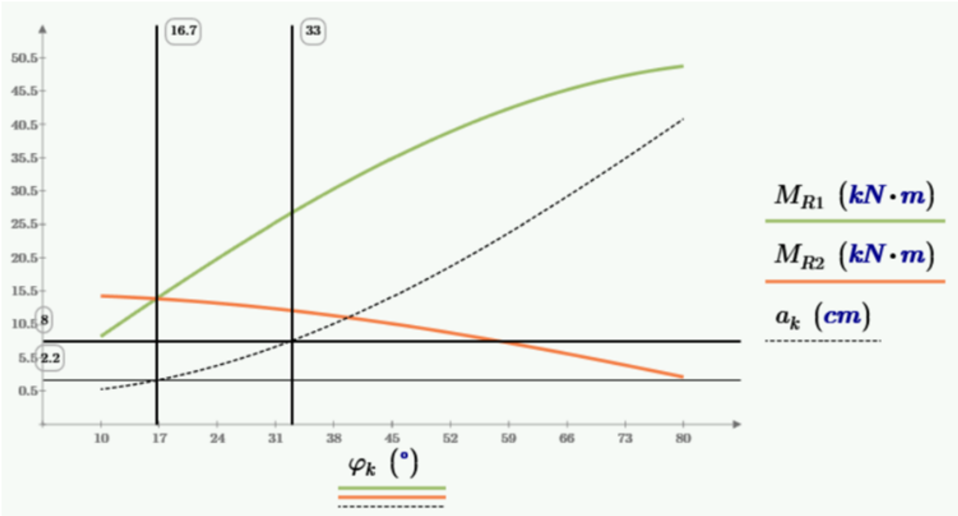


Figure 46: Limits of wedge height

- M_{R1}... Moment that prevents over rolling.
- M_{R2}... Moment that forces over rolling.

Figure 5 displays the height limits of the wedge, with a lower limit being set at a height of$a_k = 22mm(\varphi_k = 16{,}7°)$, where M_{R1} and M_{R2} hold the same value. The upper limit is $a_k = 80mm(\varphi_k = 33°)$, marking the border line of the UIC 505 Profile.

5.3.3.1.2.3 Geometry

The Wedge Brake System has been designed to fit between rails and is located below the GI2 of EN 15273-2:2013 and UIC 505 Profile. The length of the system is dependent on the number of axles that require blocking.

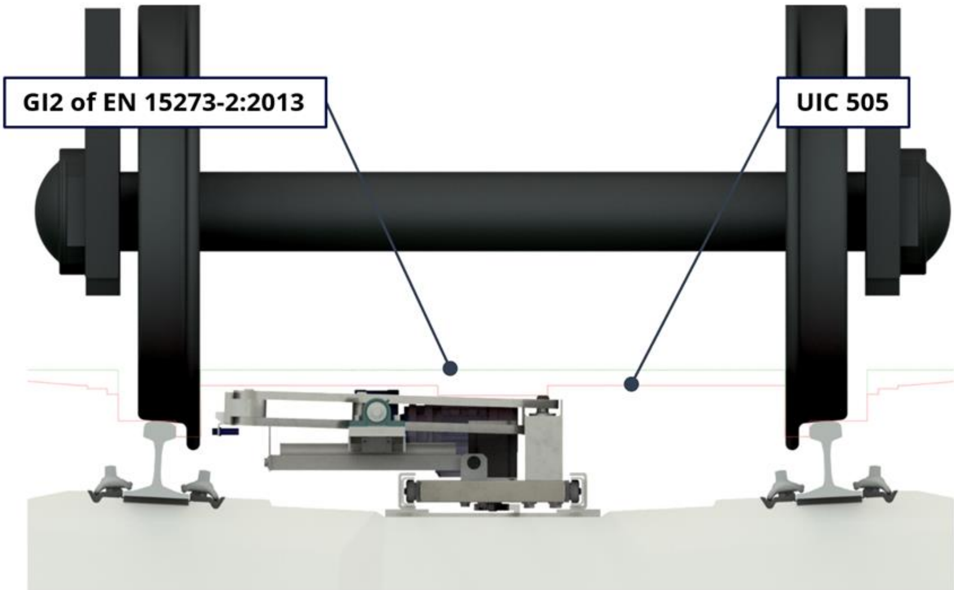


Figure 47: Deactivated Wege Brake with GI2 of EN 15273-2:2013 and UIC 505

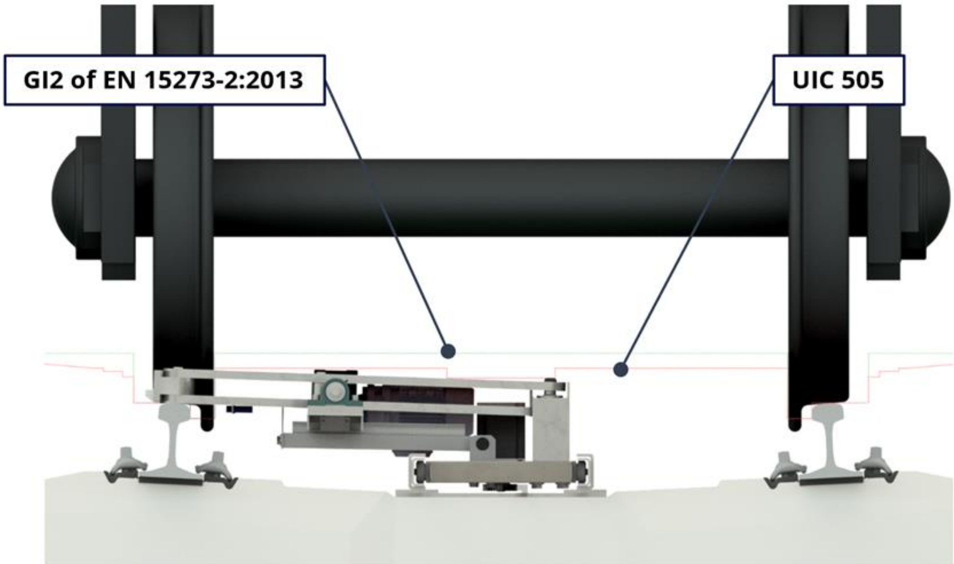


Figure 48: Activated Wege Brake with GI2 of EN 15273-2:2013 and UIC 505

5.3.3.1.2.4 Drive

The Wedge Brake System is powered by electricity. As depicted in Figure 49, two motors are affixed to the bogie. One is a stepper motor responsible for the bogie's linear movement and placement. The other is a worm geared motor that activates the wedge mechanism and applies the clamping force. In the event of a power outage, the worm geared motor retains the clamping force.

5.3.3.1.2.5 Sensors

The Wedge Brake System's bogie has two distance sensors installed at either end, allowing it to adjust its parking position. These sensors are indispensable when multiple bogies are sharing the same track. To precisely detect a wheel and place the bogie appropriately, four additional distance sensors are required on one side. These sensors also facilitate train detection and axle counting, even in the bogie's parking position. The force required to secure the wagon is measured using a current sensor that is mounted on the worm gear motor. Distance sensors are installed on the bogie to position the clamping mechanism.

5.3.3.1.2.6 Controller

The controller forms part of the Wedge Brake System and can be situated in an outdoor housing. If multiple bogies operate on the track, the system governs them all. The controller comprises a computer, with control software, measurement amplifiers, and engine controls.

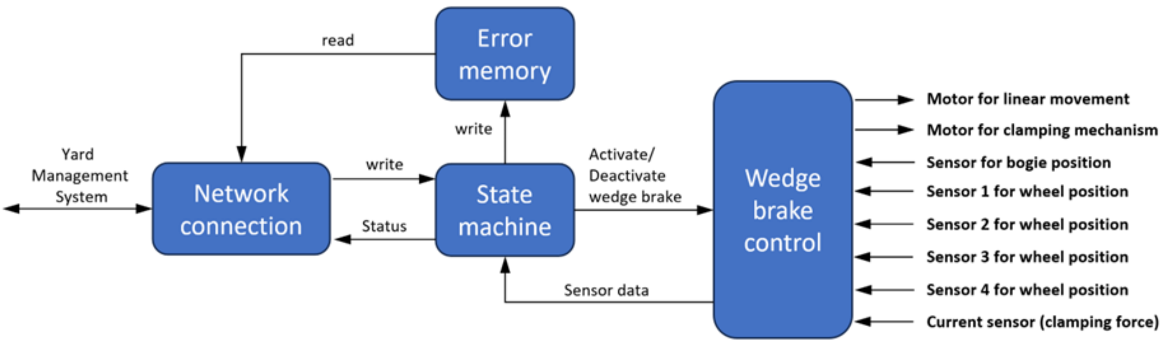


Figure 49: Control system for Wedge Brake (preliminary)

<u>Wedge brake control</u>

The functional block consists of both hardware and software components. The hardware element features the interface to the wedge brake’s sensors and actuators, encompassing measurement amplifiers, I/O modules to handle sensor input, and motor drivers to control the electric motors.

Meanwhile, the software component assesses sensor signals to assess the necessary input parameters for the state machine and control the activation and deactivation of procedures.

The software also comprises both activation and deactivation protocols. These procedures are executed exclusively on instruction from the state machine.

Table 31: Wedge Brake - activation and deactivation protocols

Activation	Deactivation
1. Start electric motor to move to the wheel needed to brake. 2. Stop electric motor when position is reached. 3. Start electric motor of clamping mechanism to clamp wheel. 4. Stop electric motor when clamping force is reached.	1. Start electric motor to deactivate the clamping mechanism. 2. Stop electric motor when end stop of mechanism is reached. 3. Start electric motor to move to parking position. 4. Stop electric motor when parking position is reached.

Error memory

The error memory holds entries for failures or malfunctions of the Wedge Brake System. Each entry comprises a timestamp, an error code that pertains to a component, event, and error type, and a flag that indicates whether the entry has already been transmitted to the hump control system.

The state machine adds the entries to the memory when in the Failure or Alarm states. When the telegram processing block reports a change in state to the hump control system and requests entries, the error memory marks them as read. This ensures that only the most recent error entries relating to the current situation are transmitted to the hump control system.

State machine

The Wedge Brake System's state is controlled by the state machine, which relies on the input parameters of surrounding functional blocks. State machine can assume the following states:

- Inactive
- Activation
- Active
- Deactivating
- Inactive
- Failure
- Maintenance

The impact of alterations between various states is ascertained whilst choosing the system for further development.

Failure mode and effects analysis is carried out when Wedge Brake System is chosen as the option for Parking Retarder.

5.3.3.2 Stationary Brake Test System and Parking Retarder

5.3.3.2.1 Operating Principle

The automatic brake test system performs the following tasks, depending on the concept, during train preparation in the marshalling yard:

- filling the wagons with compressed air after rolling off the hump with bleed wagons
- perform brake test with the functions of the DAC
- secure the wagon group
- brake the rolling wagon group to stillstand if necessary

Carrying out the brake test with the help of the vehicle of the departing train is possible but does not appear to be sensible regarding the shortest possible stay of the train vehicle before departure. Filling the train with compressed air, as well as carrying out the brake test before the loco arrives, so that in the event of any problems a repair is more easily feasible, appears to be very helpful here in terms of cost-saving and safe operational handling.

This automatic, stationary brake test system (SBTS) is designed as a kind of movable buffer with a DAC. The system can be "tilted" out of the track space to allow unhindered passage to the tracks.

Furthermore, with the help of the DAC, it not only forms a mechanical connection to the wagon group but also a direct data, power, and air connection. This means that not only compressed air can be filled, but a connection from the wagons to the yard management system can also be established.

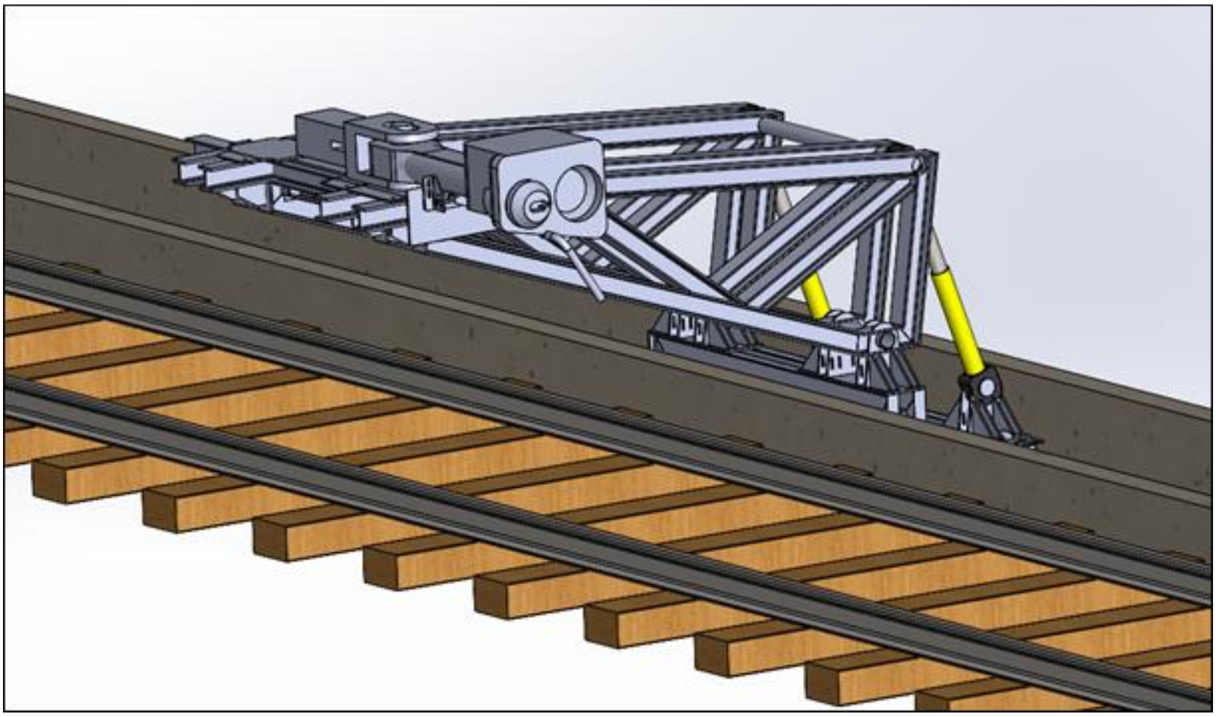


Figure 50: Stationary Brake Test System folded into the track

By folding up the DAC, the locomotive has access to the wagon groups after carrying out the brake test. During the coupling process with the locomotive, the train may have to be secured, e.g. by activating the brake of the wagon group.

When folded up, both parallel tracks can be used without restrictions.

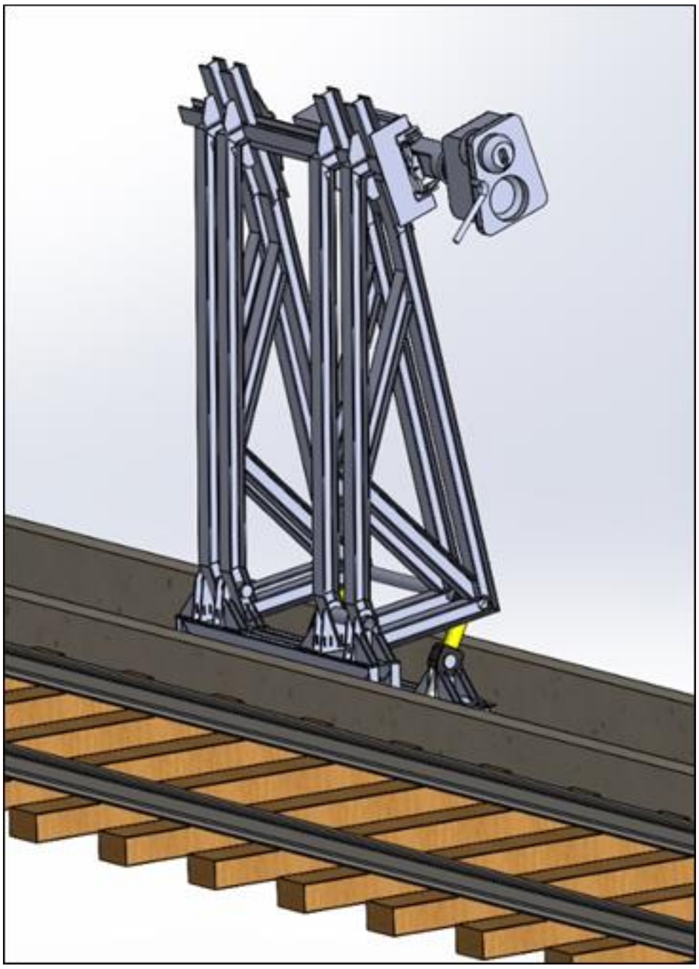


Figure 51: Stationary Brake Test System folded out of the track

The automatic brake test system can be moved in the longitudinal direction, so that it can drive to the slowly rolling wagons and bring them to a standstill and subsequently also hold them, as the wagons are automatically coupled with the DAC of the system.

In principle, the system can be designed so that one installation is applicable to two tracks. This would mean that only one out of two tracks can be used at a time, which could still be feasible for smaller yards, but is not an option for larger yards close to full capacity.

Alternatively, if the presented concept turns out to not be feasible, a similar construct could be put between the rails, underneath the clearance profile. This would be more advantageous in terms of the forces acting upon the device and it would clear the space between the rails for staff to walk through, however, installing such a device between the rails is more complicated.

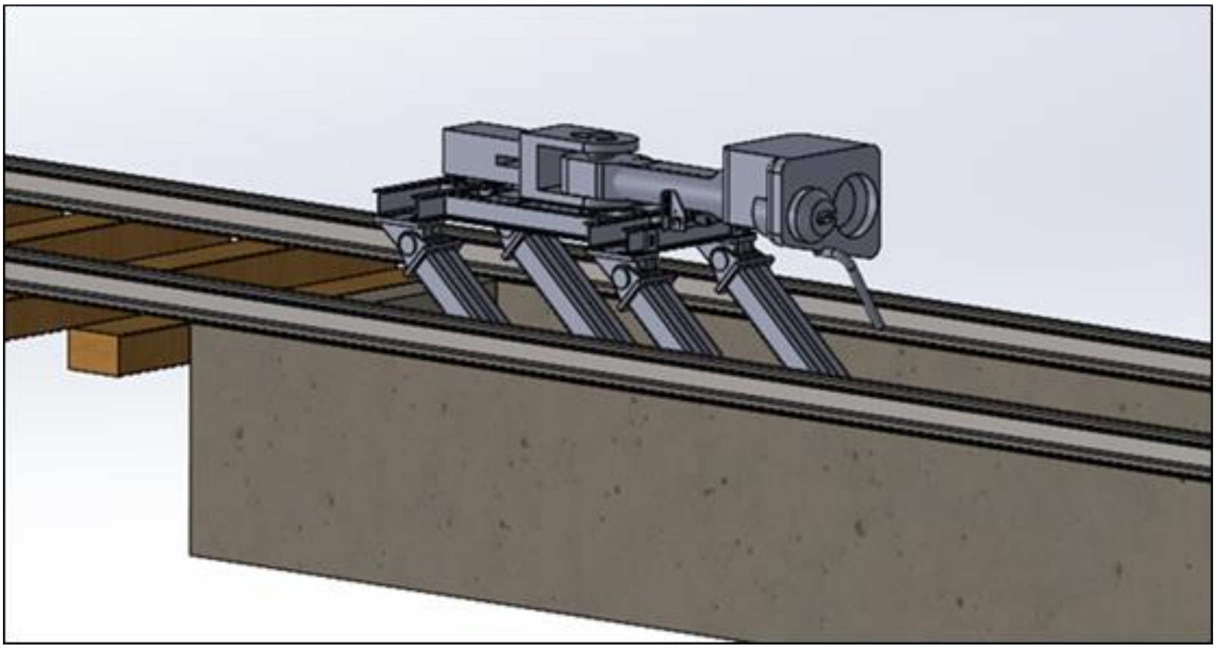


Figure 52: Stationary Brake Test System between the rails folded into the track

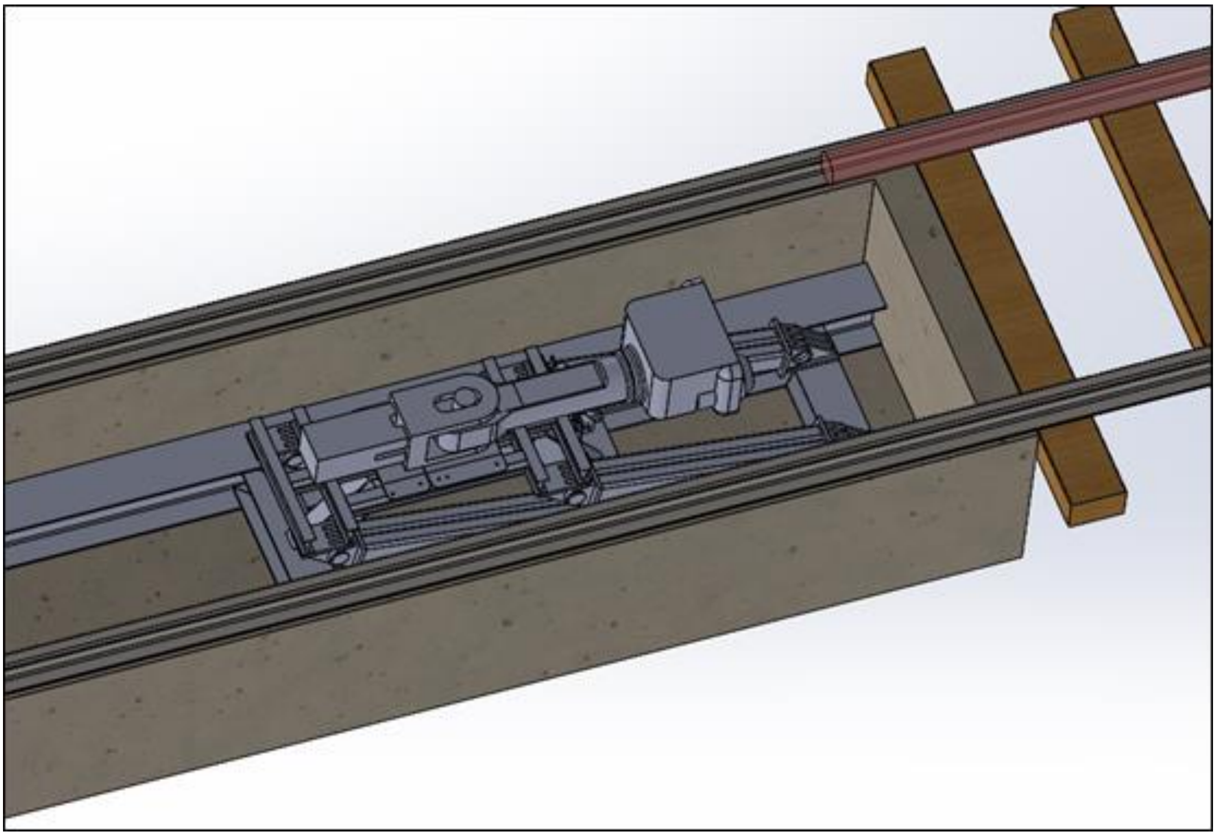


Figure 53: Stationary Brake Test System between the rails folded out of the track

5.3.4 ASO Architecture

The ASO architecture has to take into account the trackside element (ASO Trackside and Hump Control System) and the train equipment (ASO On-Board and Lead CCU).

The two systems will communicate over a standard IP protocol via ethernet or wireless.

The loco radio-modem will have two logical communication channels with different ports.

Internal architecture of Lead CCU and ASO On-Board will be supplier dependent as well as its hierarchy.

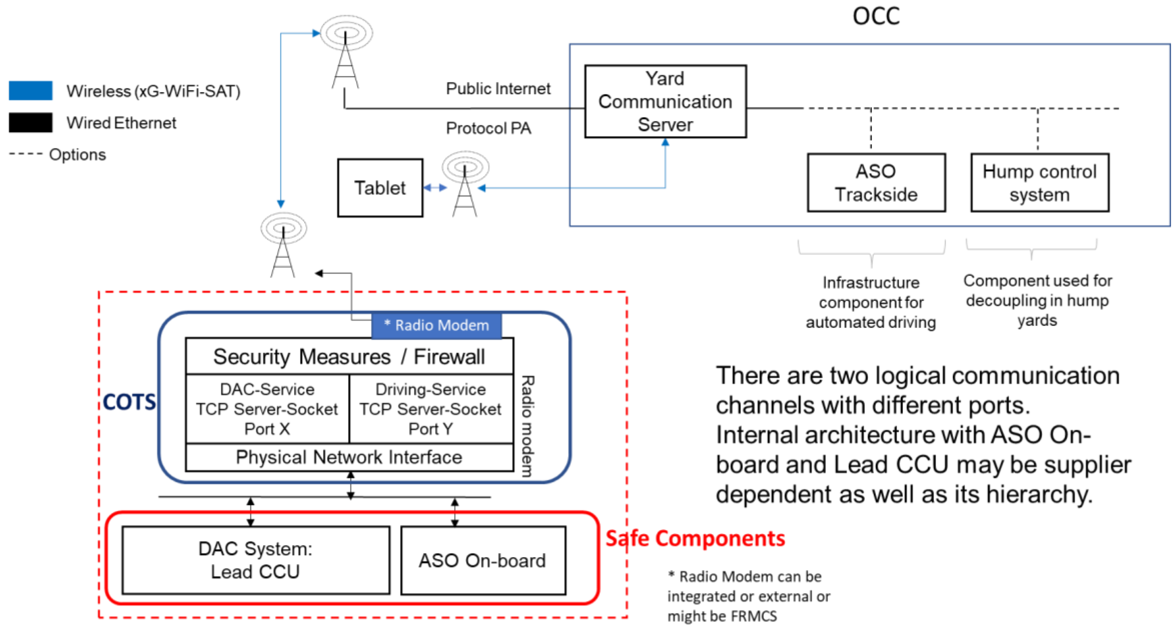


Figure 54: ASO Architecture

There are two logical communication channels with different ports.

Internal architecture with ASO and Lead CCU may be supplier dependent as well as its hierarchy.

5.3.4.1 YAS towards loco DAC & ASO

As has been already defined above and in the section on decoupling control (cf. 5.3.2.7 Telegrams) the interface between YAS and locomotive is defined as TCP/IP. The Message/telegram format has been defined as JSON.

In line with the definition in Figure 54 there are two main functional areas

- Driving Services
- DAC-Service: This has been described in considerable detail in the chapter 5.3.2.6 and 5.3.2.7

Regarding the Driving Services, the ASO requirements need to be met.

In terms of functionality the following items must be fulfilled:

5.3.4.1.1 Activation and Registration of an ASO-OBU

The sequence diagram of Figure 55 shows the procedure as followed:

- An ASO-OBU is getting activated and tries to establish a VPN-Connection to the Yard Communication Server (YCS)
- Once the Connection has been activated, the OBU transmits its local stored OBU ID to the YCS. The YCS on the other hand requests for a validity check of the given OB ID on the ASO Trackside. If the validity have been acknowledged, the YCS provides a temporary session-ID to the ASO OBU.
- The ASO OBU periodically sends a status message to the ASO Trackside (via the YCS), including its operational status and current position.
- The ASO Tracksides responses each status message back to the ASO OBU. By these means, both components can verify the reachability and availability of the other side.
- The YCS is observing the TCP/IP-Connection to the OBU. On a detected broken link, it triggers a warning message to the ASO Trackside. If the ASO OBU can reestablish the link within a certain time, the connection can be seen still as valid. If not, the YCS triggers an alert and the reestablishment of the connection is the ASO OBU´s duty.

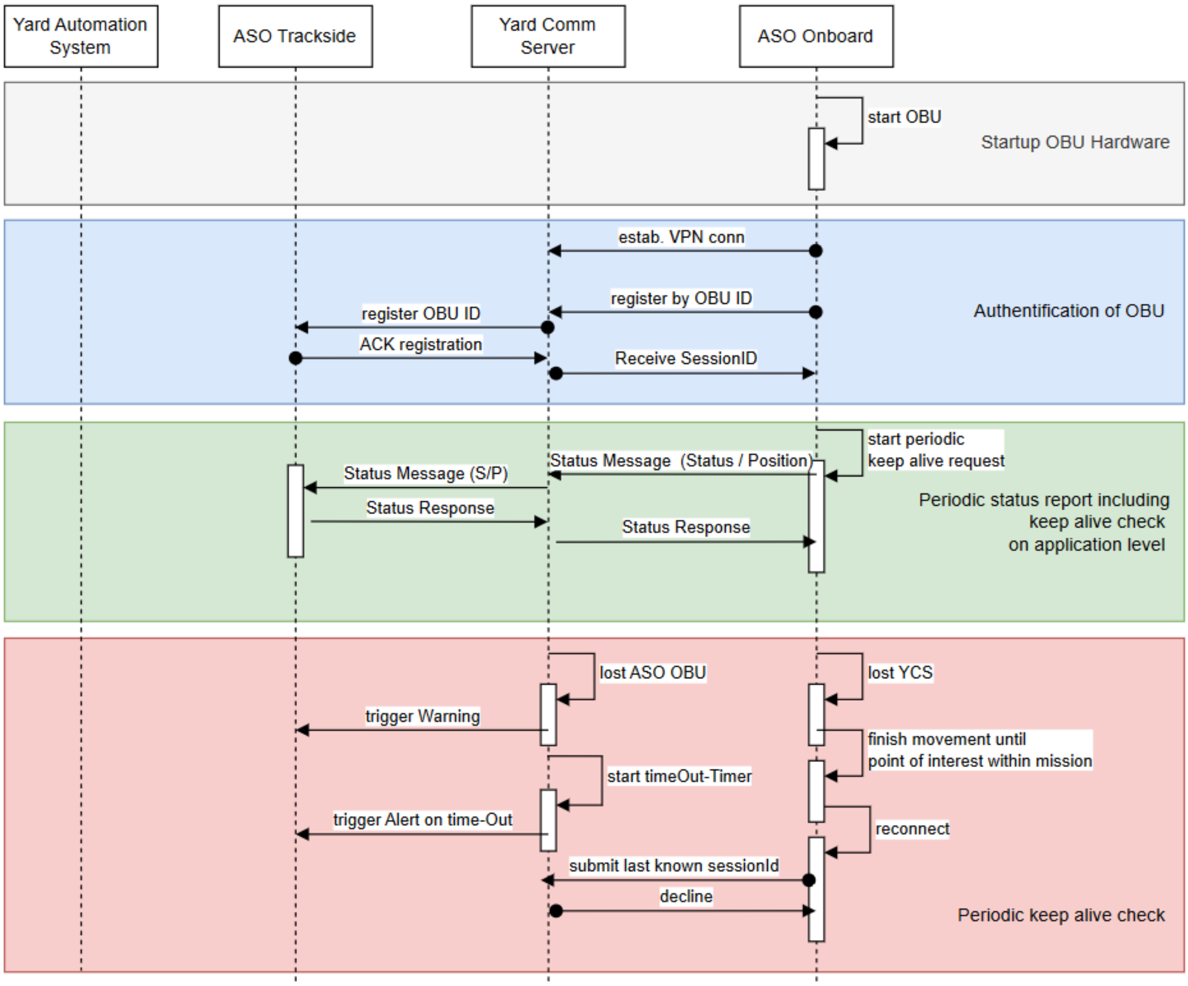


Figure 55: ASO Sequence Diagram, Connection establishment, registration

5.3.4.1.2 Transmitting of the Shunting Mission (YAS --> TU OBU)

Several components are involved when a Shunting Mission is going to be sent to the ASO-OBU. The coordination of trackside assets like points is located in the ASO-Trackside component or the YAS, supplier dependent. As Figure 56 describes, the transmission and execution of an ASO-Mission consists of the following steps.

- The YAS sends the prepared mission to the ASO-Trackside
- ASO Trackside evaluates the mission for required interactions with the interlocking system. The ASO-Tracksides might request the Interlocking System to change a switch position.
- If the track is prepared for the vehicle movement, the ASO Trackside sends the mission (via the YCS) to the ASO OBU.
- ASO OBU is triggering the vehicle control unit to execute the movement, until a certain position (Point of Interest - POI) has been reached.
- Due to the periodic and spontaneous (when a POI has been reached) status messages, the ASO Trackside is aware of the ASO-OBU conditions.
- ASO-Trackside decides if either further action from the interlocking or next missions from the YAS have to be obtained. In both cases, the ASO-OBU receives the relevant shunting missions from the ASO Trackside.
- The ASO-OBU on the other hand is triggering the Lead CCU on certain POI´s for the respective DAC-actions.

The required data exchange between trackside (YAS, interlocking, mapping) and onboard systems (positioning, remote control) shall be designed according to the interfaces & protocols defined in FP2 R2DATO (as for movements) and FP5 FPSE (as for FDFTO train functions) once the work done by respective expert groups has been properly considered.

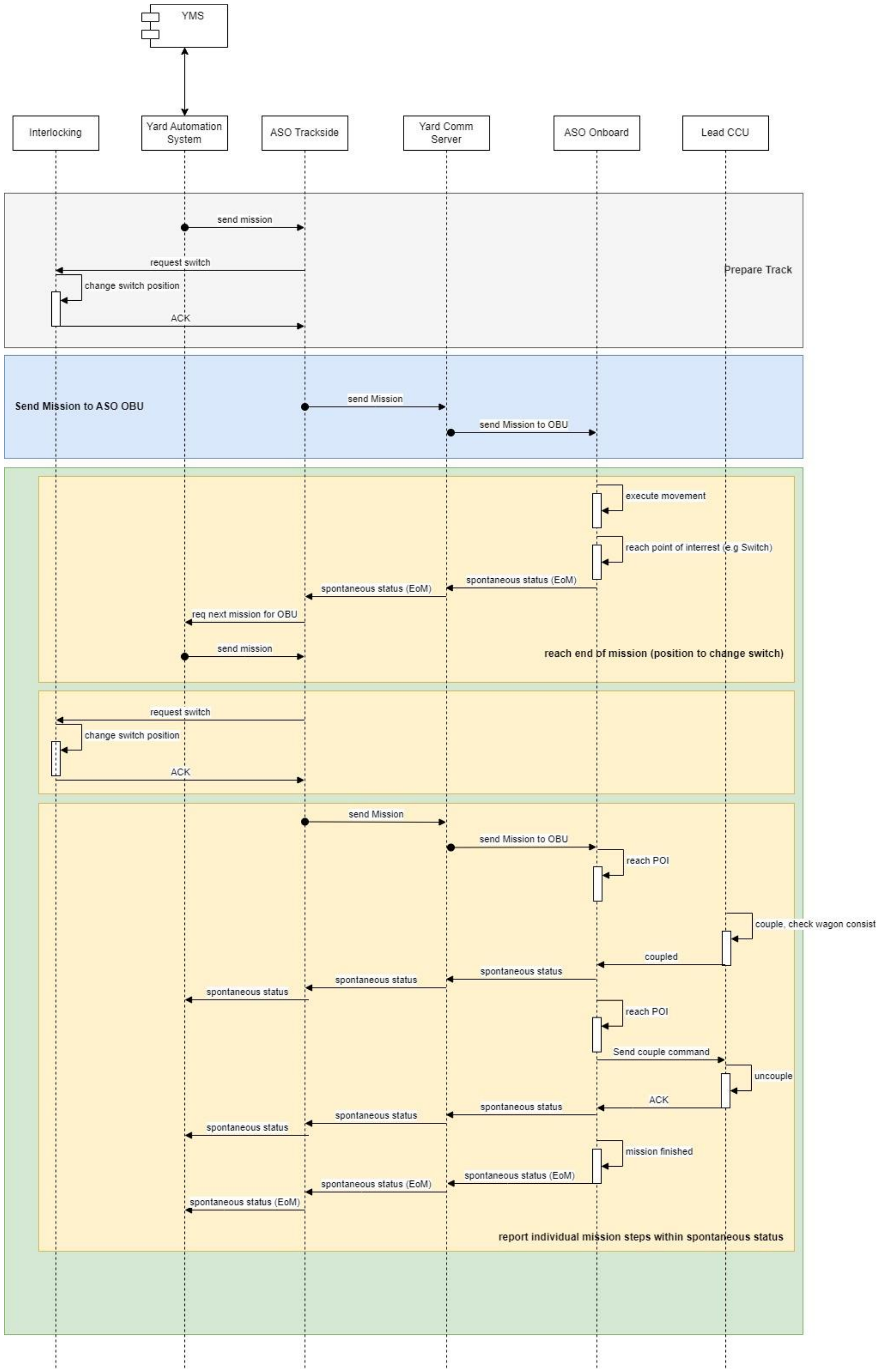

YMS
Interlocking
Yard Automation System
ASO Trackside
Yard Comm Server
ASO Onboard
Lead CCU
send mission
request switch
change switch position
ACK
Prepare Track
Send Mission to ASO OBU
send Mission
send Mission to OBU
execute movement
reach point of interrest (e.g Switch)
spontaneous status (EoM)
spontaneous status (EoM)
req next mission for OBU
send mission
reach end of mission (position to change switch)
request switch
change switch position
ACK
send Mission
send Mission to OBU
reach POI
couple, check wagon consist
coupled
spontaneous status
spontaneous status
spontaneous status
reach POI
Send couple command
uncouple
ACK
spontaneous status
spontaneous status
spontaneous status
mission finished
spontaneous status (EoM)
spontaneous status (EoM)
spontaneous status (EoM)
report individual mission steps within spontaneous status

Figure 56: Sequence Diagram, execution of a shunting mission

5.3.4.1.3 Electronic Shunting Requests ESR

Depending on the level of automation, missions can be manually obtained from the ASO Trackside by means of an ESR, as shown in Figure 57.

- The ASO OBU receives a list of missions, which are foreseen for the respective TU.
- As soon as the TU is ready for the first mission, the first mission will be requested to be processed by the ASO OBU by sending an ESR to the YAS.
- The ASO Trackside checks if any interaction with the interlocking is required, before it will respond the ESR with the first mission.
- The end of the mission will be indicated by a spontaneous status message from the ASO OBU.
- For further missions, the process repeats by sending an ESR from the ASO OBU to the ASO Trackside, if the TU and staff is ready.

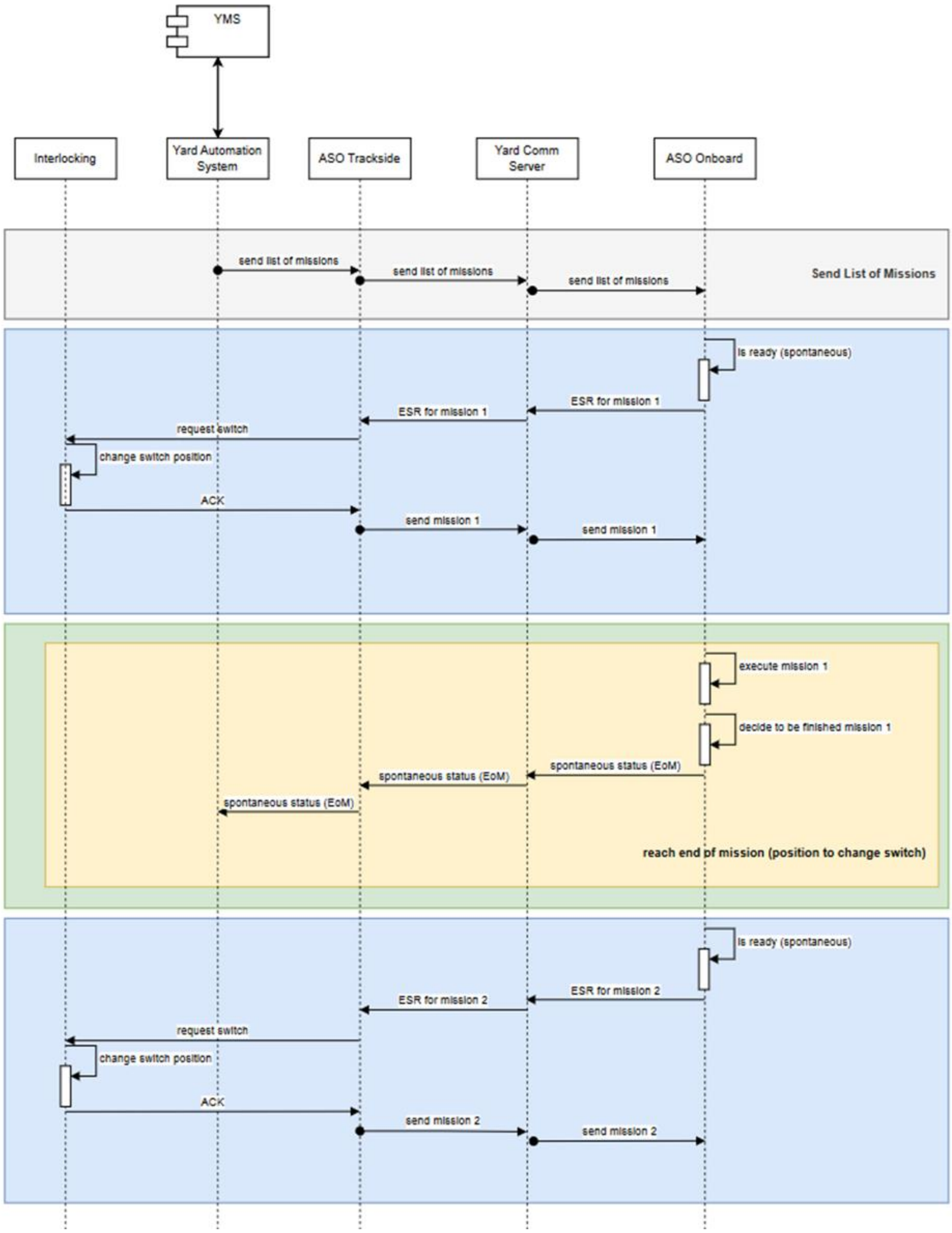


Figure 57: Electronic Shunting Request ESR

5.3.4.1.4 Optional Service Request

This telegram could be combined with the shunting mission if additional services are requested, e.g. (not exhaustive, multiple combinations possible)

- Automatic Brake Test by a system on-board of the shunting loco
- Brake air reservoir filling
- Brake venting
- Etc.

5.3.4.1.5 Optional Emergency Stop requests

If the yard is equipped with obstacle detection equipment as part of the yard infrastructure and the shunting path is detected to be blocked by an obstacle

- Obstacle based emergency stop order (Interrupt/Revocation of mission order)

5.3.4.1.6 Revocation of Shunting mission

If the system detects any anomaly or there are other reasons to stop the ongoing shunting process, the YAS shall transmit a revocation of movement authority whereupon the ASO-TU shall stop.

5.3.4.1.7 Electronic Shunting Request

Depending on the level of automation, it might be preferable to request missions for specific TU manually. For this reason, a ASO OBU receives a list missions, which are foreseen for this TU. As soon as TU and staff is ready for a mission, a specific mission to be executed will be requested by sending an ESR to the YAS. The mission will be executed by the TU and reported as finished (EOM) to the YAS. Again, if the TU and staff is ready for the next mission, it will be requested via ESR from the YAS.

5.4 Catalogue of Trackside Requirements for Shunting & Train Preparation

5.4.1 **Automated stationary brake test system and parking retarder for the classification tracks**

5.4.1.1 Automated stationary brake test

This specification lists the technical requirements for the development of a stationary, infrastructure-based device able to perform an automated brake test. This list is limited to the requirements necessary to fulfil the function of performing a brake test.

Table 32: Technical requirements Brake Test Device

ID	REQ Type	Object Text	Rationale	Status
	informative	Brake tests are time consuming and, if performed by a TU, quite expensive, as TUs are generally used to their full capacity already. As such, stationary brake test devices are often installed in the tracks of larger shunting yards, so staff can perform a preliminary brake test with all the wagons without the need of a TU. This way, if there is an issue with a wagon, it can be fixed before a TU arrives to pick the wagons up, reducing delays and freeing up TUs as a resource.		-
	informative	However, performing this brake test currently still requires staff. With the introduction of the DAC, an opportunity presents itself to automate this process step as well. The purpose of this list is to lay out the		-

		requirements for a system able to automatically perform this brake test without the need for manual intervention.		
	informative	It is assumed that the wagons are equipped with sensors that can verify the performance of the brakes, as it does not seem feasible to verify this autonomously from the infrastructure side.		-
	informative	This means that the system shall be able to essentially simulate a TU for the purpose of performing the brake test.		-
ASBT-1	functional	The device must be able to perform a brake test with all coupled wagons and without a TU.	Main purpose of the system and boundary	-
ASBT-2	functional	The device shall be able to control the brakes of the coupled wagons.	Main purpose of the system and boundary	-
ASBT-3	functional	The device must be able to refill the brake reservoirs of the arriving wagons if they have been bled.	Main purpose of the system and boundary	-
ASBT-4	functional	All functions of the device must be controllable by a remote control without the manual intervention of a shunting employee. This includes control via a YAS.	Necessary for integration into yards and autonomous operation.	-
ASBT-5	functional	In the event of a failure of a component or the power supply of the device, the device must have a fallback level to ensure safe operation.	The failure of the device should not impact the operation of the entire yard too much.	-
ASBT-6	functional	The correct function/performance of the device must be verifiable by trained persons or systems, both on-	Necessary for safe operation.	-

		site and remotely.		
ASBT-7	functional	In the inactive state, the device shall comply with the boundary line GI2 of EN 15273-2:2013.	The profile allows all kind of rail vehicles to pass the device without geometrical conflicts.	-
ASBT-8	functional	The device shall not put wagons at risk for derailment in any of its states.	Derailment safety.	-
ASBT-9	functional	The device shall not damage rail vehicles. Expectable signs of abrasive wear are excluded.	The lifespan of rail vehicles or their components must not be reduced due to the introduction of new systems.	-
ASBT-10	functional	The device shall be operated under climate conditions defined by climate class 4K26 according to EN IEC 60721-3-4:2019.	Climate class 4K26 describes an outdoor environment for locations with arid and moderate climate including temperatures -20°C and +50°C.	-
ASBT-11	functional	The device shall be certified according to ATEX regulations. Device group II and equipment protection level Gc according to DIN EN IEC 60079-0:2019-09 shall be achieved.	Freight wagons may transport hazardous goods such as gas that can leak into the environment. For these failure cases, it is required that a device interacting with them is not contributing to explosions.	

ASBT-12	functional	If applicable, the device shall fulfil requirements for electromagnetic compatibility according to DIN EN 50121-4:2017-11.	Required by European regulations, ensures electromagnetic compatibility of device and prevents influence on other devices.	-
ASBT-13	functional	If the device uses hydraulic oil or lubrication grease, national laws and regulation for the protection of water shall be considered.	Hydraulic oil and lubrication grease may have an impact on the environment if significant leakages appear.	
ASBT-14	functional	The device shall have a maintenance mode ensuring no operation if not triggered by maintenance staff on place.	Prevention of accidents and injuries	-
ASBT-15	functional	The device shall conform to the European directive on machinery 2006/45 and its translation into national law of the country of deployment.	Conformity is required for commercial product, part of CE-conformity	-

5.4.1.2 Parking retarder for the classification tracks

This specification lists the technical requirements for the development of an infrastructure-based stationary parking brake located in the classification tracks of a hump yard. This differentiates it from the list of 5.4.2, as that is only meant for the entry group of the yard. The device described in 5.3.2 therefore fulfils the requirements of both this list as well as the one specified in 5.4.1.1.

Table 33: Technical requirements Parking Retarder

ID	REQ Type	Object Text	Rationale	Status
	informative	Currently in a hump yard the wagons roll over the hump and are sorted into their correct tracks. The first arriving wagon or wagon group of a new train has to be brought to a stop in the classification track in some way - currently the most common method is that staff lay out parking shoes on the track. Following wagons roll onto this stopped wagon and are, as necessary, secured additionally using more parking shoes or parking brakes.		-
	informative	To avoid this manual task new systems are to be developed that can perform this task autonomously. This involves bringing the first wagon group to a stand-still and sufficiently securing any further arriving wagons. This list is to specify the requirements for such a system further.		-
	informative	This list should not contradict the specified requirements list for parking retarders in the entry group, however, certain differences, especially the braking of wagons to a stand-still, do exist.		-

PRCT-1	functional	The system shall be able to brake wagon groups rolling into a classification track after being rolled over the hump to a stand-still.	Main purpose of the system and boundary.	-
	informative	The wagon groups rolled over the hump shall have a maximum allowed weight and shall be braked down to a maximum velocity before entering their respective classification track. These exact technical specifications still have to be evaluated, as they are currently different in each country and even in each yard within a country.		-
PRCT-2	functional	The system shall be able to secure rail vehicles that have been brought to a stand-still by it in a classification track.	Main purpose of the system and boundary	-
	informative	The system may utilise the normal brakes of the wagons, the controllable parking brake of the wagons or its own separate mechanism to secure these wagons. The wagons shall be secured for an indefinite amount of time, given that an energy supply remains available.		-
PRCT-3	functional	The system should provide a method to bring wagons that stopped early in the track before reaching the rest of the wagons to the already arrived wagons.	Main purpose of the system and boundary.	-
	informative	Some yards already use automated systems like this, also to push wagons together for easier coupling. The system described here should provide a similar mechanism, as otherwise unsecured wagons are essentially rolling around in the track.		-
PRCT-4	functional	The system shall have interfaces to superordinate systems. The superordinate systems are located outside of the system boundaries.	External interface as system boundary	-

PRCT-5	functional	The retarder shall have at least two mechanical states: (1) An active state that prevents the movement of rail vehicles and (2) an inactive state that allows free passage of rail vehicles.	Obvious states for purpose of prevention of unintentional movements	-
PRCT-6	functional	In the inactive state, the parking retarder shall comply with the boundary line GI2 of EN 15273-2:2013.	The profile allows all kind of rail vehicles to pass the retarder without geometrical conflicts.	-
PRCT-7	functional	The parking retarder shall require less than 2380 mm of space towards the side of the track, measured from centre line of the track. Refer to Figure 59.	Installed components shall fit into the space between two adjacent tracks. In Germany, two adjacent tracks are located at a minimum of 4000 mm, measured from centre line to centre line. Refer to EBO, §10, Sec. (3). The boundary line GI2 according to EN 15273 requires 1620 mm from the track centre line above a height of 400 mm. Hence, a value of 2380 mm is available under the assumption that the retarder solution will only be installed on one side of the track.	-
PRCT-8	functional	If the retarder is designed as beam retarder, the track radius at the location of installation shall not be smaller than 190m.	Constructional constraints of beam retarders	-
PRCT-9	functional	If the retarder is designed as beam retarder, the track radius shall remain constant at the location of installation.	Constructional constraints of beam retarders	

PRCT-10	functional	If the retarder is designed as beam retarder, the track gradient shall remain constant at the location of installation.	Constructional constraints of beam retarders	-
PRCT-11	functional	The track section where the parking retarder is installed shall conform to the regular track superstructure, valid in the country of installation. No additional elements such as guide rails shall be in the track section.	Installation method designed only for regular track superstructure	
PRCT-12	functional	The minimum holding force shall be dimensioned according to §25, Sec 2 of DA 30.04.20:V6.0. The minimum holding force depends on the maximum track gradient and train mass. Hence, the required value depends on the location, designated for installation.	Minimum forces are required to keep the train safely in the track.	-
PRCT-13	functional	The applied holding force shall be effective in both directions.	Forces induced by wind can change direction	-
PRCT-14	functional	When the parking retarder is in the active state, the holding force shall be kept regardless the availability of the interfaces.	In case of interruption of interfaces (el. Power, hydraulics, or data), the parking retarder must not change into an inactive state.	-
PRCT-15	functional	When the parking retarder is in inactive state, the design of the retarder shall ensure that a self-activation (not commanded from the controller) is not possible.	When the parking retarder is in active state, it can be an obstacle for passing rail vehicles. Wheels may lift from the rail. Hence, it is necessary to ensure that the retarder remains in inactive position.	-
PRCT-16	functional	The parking retarder shall not put wagons at risk for derailment in any of its states.	Derailment safety	-

PRCT-17	functional	The retarder shall not damage rail vehicles - both in active and inactive state. Expectable signs of abrasive wear are excluded.	The lifespan of rail vehicles or their components must not be reduced due to the introduction of parking retarders.	-
PRCT-18	functional	The parking retarder shall be operated under climate conditions defined by climate class 4K26 according to EN IEC 60721-3-4:2019.	Climate class 4K26 describes an outdoor environment for locations with arid and moderate climate including temperatures -20°C and +50°C.	-
PRCT-19	functional	The parking retarder shall be certified according to ATEX regulations. Device group II and equipment protection level Gc according to DIN EN IEC 60079-0:2019-09 shall be achieved.	Freight wagons may transport hazardous goods such as gas that can leak into the environment. For these failure cases, it is required that a parking retarder is not contributing to explosions.	-
PRCT-20	functional	The parking retarder shall not emit noise above 50dB(A) in active or in inactive state, measured 1m from the retarder.	In case of residential areas in the neighbourhood, people might feel disturbed by a constant noise level. A level of 50 dB corresponds to the noise level of a normal conversation. The noise immission is lower as the noise level decreases by 6dB with every doubling of the distance to the retarder.	-
PRCT-21	functional	The parking retarder shall not emit noise above 75dB(A) in the phases of activation, deactivation and when rail vehicles drive/roll through the parking retarder, measured 1m from	The temporary noise level during activation and deactivation may be higher. A level of 75 dB corresponds	-

		the retarder.	to the noise level of car passing by. The noise immission is lower as the noise level decreases by 6dB with every doubling of the distance to the retarder.	
PRCT-22	functional	If applicable, the parking retarder shall fulfil requirements for electromagnetic compatibility according to DIN EN 50121-4:2017-11.	Required by European regulations, ensures electromagnetic compatibility of parking retarder and prevents influence on other devices.	-
PRCT-23	functional	If the retarder uses hydraulic oil or lubrication grease, national laws and regulation for the protection of water shall be considered.	Hydraulic oil and lubrication grease may have an impact on the quality of ground water if significant leakages appear.	-
PRCT-24	functional	The parking retarder shall conform to the European directive on machinery 2006/45 and its translation into national law of the country of deployment.	Conformity is required for commercial product, part of CE-conformity	-
PRCT-25	Non-functional	The tolerable hazard rate for an unintentional deactivation of the parking retarder shall be less than $1e^{-6}$ 1/h.	Standard hazard rate for functions in yards	-
PRCT-26	Non-functional	The tolerable hazard rate for an unintentional activation of the parking retarder shall be less than $1e^{-6}$ 1/h.	Standard hazard rate for functions in yards	-

5.4.2 Stationary parking brake

This report deals with an infrastructure-based parking retarder, deemed necessary as a safety device in marshalling yards. Its application is in the entry group of such yards, where trains or consists arrive and are stopped at a predetermined track The stopping process uses the normal indirect pneumatic brake of the train.

According to current rules and regulations the waggon/train consist must be secured thereafter against inadvertent/unintended and unattended rolling if it is foreseeable that the parking duration exceeds a period defined by national and/or local rail regulations.

This is mainly due to the fact that the pneumatic brake system may lose air pressure over time either due to leakage or changed ambient parameters.

Bleeding of wagons as part of shunting preparation for hump shunting may be another reason for introducing stationary parking brakes, unless bleeding can be done automatically shortly before hump operation starts.

One of the objectives and expected benefits of introducing the DAC is the capability to design a reliable and cost-effective wagonside parking brake which may be activated via the DAC-Controller of the traction unit or any authorized remote control system.

However, the relevant TSI regulation published via COMMISSION DECISION of 28 July 2006 concerning the technical specification of interoperability relating to the subsystem 'rolling stock — freight wagons' of the trans-European conventional rail system (notified under document number C(2006) 3345) states in Position 4.2.4.1.2.8. Parking Brake 2nd paragraph:

„It is not compulsory for all wagons to be equipped with a parking brake. Operational rules, taking into account the fact that not all wagons in a train are equipped with these brakes, are described in the Traffic Operation and Management TSI." [1]

Thus, a considerable share of the current freight wagon fleet up to 80% is not equipped with a parking brake.

There is a significant chance that even with the introduction of the DAC there will be trains that cannot be secured using a train-based automatic parking brake either due to a complete lack of parking brakes or an insufficient quantity to ensure the necessary holding force, necessitating as per current operating regulations of rail operators and infrastructure managers that such trains be secured with brake shoes.

On the other hand, the core motive for the introduction of the DAC is the automation of train preparation services and thus, the reduction or - where possible - the elimination of shunting staff from moving between tracks to perform necessary services. Setting and removing brake shoes is such a service that would have to remain, if not all or at least a sufficient fraction of railcars is equipped with a functioning automatic park brake.

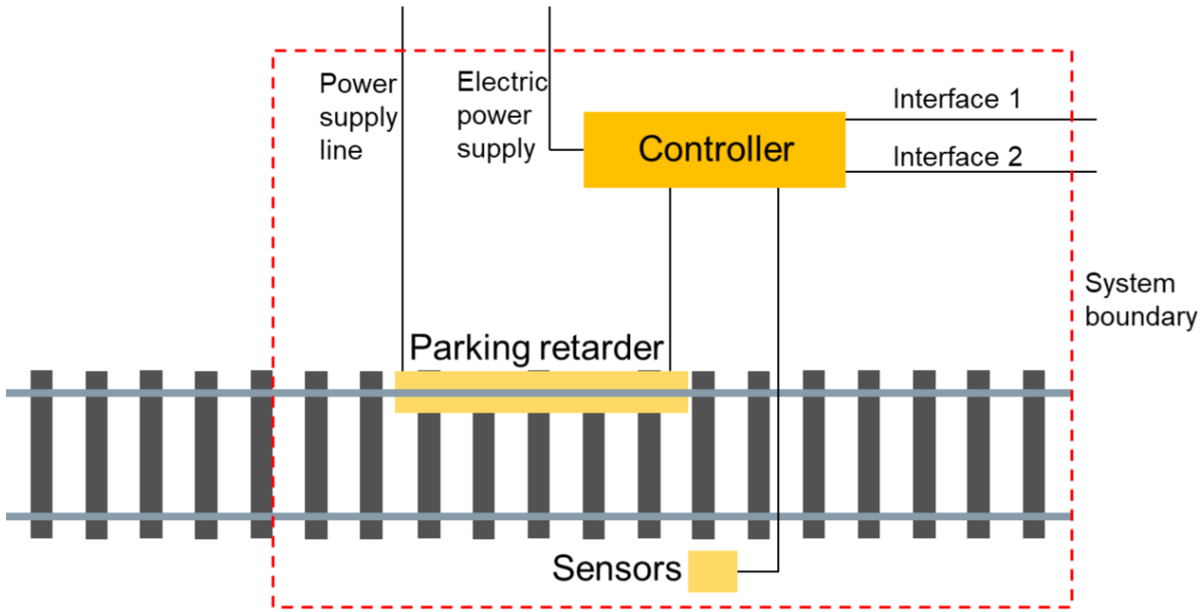
Operating patterns of most railway operators tend to favour hub-spoke models which enable concentration of staff and equipment in fewer locations. If no automation solution is developed for securing incoming trains or consists once parked on the track, full shunting teams will have to remain around the clock on these key hub locations despite the fact that their "utilisation rate" may go down.

[1] COMMISSION DECISION of 28 July 2006, 2006/861/EC, Published in the OJ of the European Union, L344/1, p.53

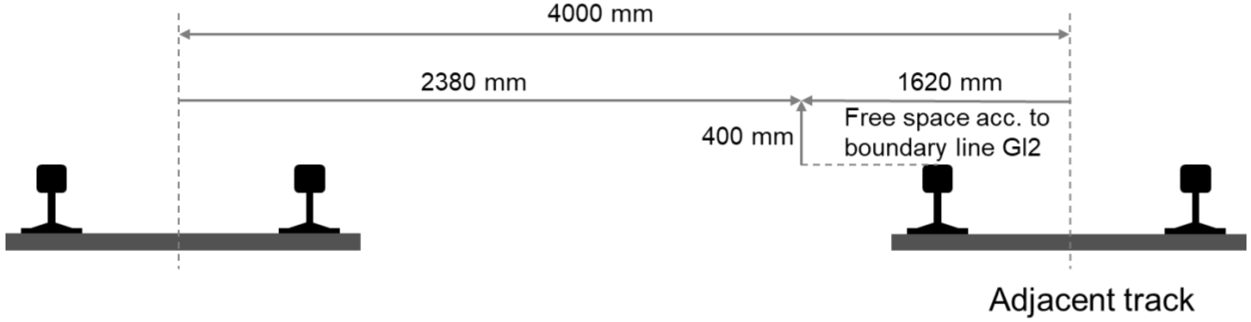
This specification lists technical requirements for the development of a stationary parking brake including a controller, both located on the infrastructure side. The document is derived from the operational concept with use cases as source of input (see section 5.2.3). In order to distinguish clearly from the on-board parking brake, which is also scope of this TRANS4M-R project, the stationary parking brake is referred to as parking retarder in this section.

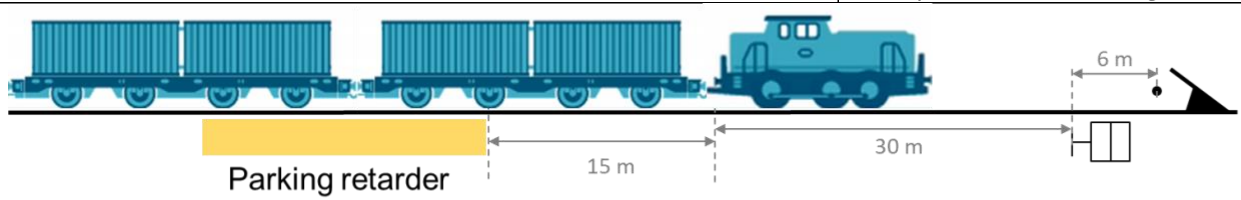
Table 34: Technical requirements Parking Retarder

ID	REQ Type	Object Text	Rationale	Status
5.4.2.1 System definition				
	informative	Rail vehicles such as freight wagons are parked in yards, terminals and sidings for longer periods - from a few hours to several days. Without the usage of onboard parking brakes or permanent air supply, there is a risk that these rail vehicles will be freely movable after time. Air reservoirs of freight wagons that are prepared for humping or fly shunting in yards are even intentionally bleeded in order to have free running characteristics. Forces created by track gradients or wind can then lead to unintentional movements.		-
	informative	Today, brake shoes are applied in order to secure rail vehicles in a track. However, brake shoes have to be set and removed manually on/from the rails which is not desired in the future as operators face a lack of personnel.		-
	informative	Activities of EU-Rail JU aim to introduce an on-board parking brake for freight wagons that would solve the problem in the future as it is digitally controlled and does not rely on pneumatic air supply. It is however expected that many years of introduction to the European wagon fleet are required to reach a 100% coverage.		-
	informative	As an intermediate solution, a parking retarder based on the infrastructure side can serve as an option to secure rail vehicles in the track and by doing so avoid manual work.		-
TRPR-1	functional	The system shall be able to secure parked rail vehicles in a track in the entrance group of marshalling yards against unintentional movements. Braking moving rail vehicles to stand-still is not within the scope of the system.	Main purpose of the system and boundary	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-2	functional	The system shall consist of at least one retarder solution installed in the track area and a corresponding controller. Refer to Figure 58.	Consist of system	-
	informative	 **Figure 58: System definition and system boundaries**		-
TRPR-3	functional	The controller shall have interfaces to superordinate systems. The superordinate systems are located outside of the system boundaries. Recommendations for these systems are mentioned in section 5.4.2.6.	External interface as system boundary	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-4	functional	The system shall have sensors used to determine whether or not wagons are located within the retarder.	Required for evaluation of active and alarm state	-
TRPR-5	functional	The retarder shall have at least two mechanical states: (1) An active state that prevents the movement of rail vehicles and (2) an inactive state that allows free passage of rail vehicles.	Obvious states for purpose of prevention of unintentional movements	-
5.4.2.2 Parking retarder				
	informative	This chapter lists requirements for the retarder solution.		-
5.4.2.2.1 Geometrical requirements				
TRPR-6	functional	In the inactive state, the parking retarder shall comply with the boundary line GI2 of EN 15273-2:2013.	The profile allows all kind of rail vehicles to pass the retarder without geometrical conflicts.	-
TRPR-7	functional	The parking retarder shall require less than 2380 mm of space towards the side of the track, measured from centre line of the track. Refer to Figure 59.	Installed components shall fit into the space between two adjacent tracks. In Germany, two adjacent tracks are located at a minimum of 4000 mm, measured from centre line to centre line. Refer to EBO, §10, Sec. (3). The boundary line GI2 according to EN 15273 requires 1620 mm from the track centre line above a height of 400 mm. Hence, a value of 2380 mm is available under the assumption that the retarder solution will only be installed on one side of the track.	-

ID	REQ Type	Object Text	Rationale	Status
	informative	 **Figure 59: Installation space**		-
TRPR-8	functional	The length of the parking retarder in trackwise direction should be dimensioned to avoid exact positioning of the train that stops within the range of the parking retarder.	Comfortable arriving procedure in the yard	-
	informative	If the parking retarder interacts with the wheels after activation, a length of 21 m will be required to ensure that at least one axle is always located within the parking retarder.		-
TRPR-9	functional	If the length of the parking retarder in trackwise direction is dimensioned so that positioning of the stopping train is required, a retarder signal should be considered. Refer to section 5.4.2.5.	The retarder signal is an option assisting the driver to stop the train at a location at which the parking retarder can interact with the wagons or their wheels.	-

ID	REQ Type	Object Text	Rationale	Status
5.4.2.2.2	Requirements for location of installation			
TRPR-10	functional	The parking retarder shall be placed at least 51 m from the fouling point. Refer to Figure 60.	Typically, signals are placed 6 m from the fouling point. The parking retarder should not interact with the locomotive, as the locomotive typically leaves the track after parking the wagons. It is rather suggested that the parking retarder interacts with the rear axle(s) of the first wagon. An additional 30 m are kept free for the locomotive, an additional 15m for a part of the first wagon.	-
	informative	 **Figure 60: Arrangement of parking retarder in track**		-
TRPR-11	functional	If the retarder is designed as beam retarder, the track radius at the location of installation shall not be smaller than 190m.	Constructional constraints of beam retarders	-
TRPR-12	functional	If the retarder is designed as beam retarder, the track radius shall remain constant at the location of installation.	Constructional constraints of beam retarders	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-13	functional	If the retarder is designed as beam retarder, the track gradient shall remain constant at the location of installation.	Constructional constraints of beam retarders	-
TRPR-14	functional	The track section where the parking retarder is installed shall conform to the regular track superstructure, valid in the country of installation. No additional elements such as guide rails shall be in the track section.	Installation method designed only for regular track superstructure	-
5.4.2.2.3 Functional requirements				
TRPR-15	functional	The minimum holding force shall be dimensioned according to §25, Sec 2 of DA 30.04.20:V6.0. The minimum holding force depends on the maximum track gradient and train mass. Hence, the required value depends on the location, designated for installation.	Minimum forces are required to keep the train safely in the track.	-
TRPR-16	functional	The applied holding force shall be effective in both directions.	Forces induced by wind can change direction	-
TRPR-17	functional	When the parking retarder is in the active state, the holding force shall be kept regardless the availability of the interfaces.	In case of interruption of interfaces (el. Power, hydraulics, or data), the parking retarder must not change into an inactive state.	-
TRPR-18	functional	When the parking retarder is in inactive state, the design of the retarder shall ensure that a self-activation (not commanded from the controller) is not possible.	When the parking retarder is in active state, it can be an obstacle for passing rail vehicles. Wheels may lift from the rail. Hence, it is necessary to ensure that the retarder remains in inactive position.	-
TRPR-19	functional	The parking retarder shall not put wagons at risk for derailment in any of its states.	Derailment safety	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-20	functional	The retarder shall not damage rail vehicles - both in active and inactive state. Expectable signs of abrasive wear are excluded.	The lifespan of rail vehicles or their components must not be reduced due to the introduction of parking retarders.	-
5.4.2.2.4 Environmental conditions				
TRPR-21	functional	The parking retarder shall be operated under climate conditions defined by climate class 4K26 according to EN IEC 60721-3-4:2019.	Climate class 4K26 describes an outdoor environment for locations with aride and moderate climate including temperatures -20°C and +50°C.	-
TRPR-22	functional	The parking retarder shall be certified according to ATEX regulations. Device group II and equipment protection level Gc according to DIN EN IEC 60079-0:2019-09 shall be achieved.	Freight wagons may transport hazardous goods such as gas that can leak into the environment. For these failure cases, it is required that a parking retarder is not contributing to explosions.	-
TRPR-23	functional	The parking retarder shall not emit noise above 50dB(A) in active or in inactive state, measured 1m from the retarder.	In case of residential areas in the neighbourhood, people might feel disturbed by a constant noise level. A level of 50 dB corresponds to the noise level of a normal conversation. The noise immission is lower as the noise level decreases by 6dB with every doubling of the distance to the retarder.	-

ID	REQ Type	Object Text	Rationale	Status
TRTR-24	functional	The parking retarder shall not emit noise above 75dB(A) in the phases of activation, deactivation and when rail vehicles drive/roll through the parking retarder, measured 1m from the retarder.	The temporary noise level during activation and deactivation may be higher. A level of 75 dB corresponds to the noise level of car passing by. The noise immission is lower as the noise level decreases by 6dB with every doubling of the distance to the retarder.	-
TRPR-25	functional	If applicable, the parking retarder shall fulfil requirements for electromagnetic compatibility according to DIN EN 50121-4:2017-11.	Required by European regulations, ensures electromagnetic compatibility of parking retarder and prevents influence on other devices.	-
TRPR-26	functional	If the retarder uses hydraulic oil or lubrication grease, national laws and regulation for the protection of water shall be considered.	Hydraulic oil and lubrication grease may have an impact on the quality of ground water if significant leakages appear.	-
5.4.2.2.5 Workers' Safety				
TRPR-27	functional	The parking retarder shall have a maintenance mode ensuring no operation if not triggered by maintenance staff on place.	Prevention of accidents and injuries	-
TRPR-28	functional	If the parking retarder is designed as beam retarder, it shall not be entered by persons except in maintenance mode.	Prevention of accidents and injuries	-
TRPR-29	functional	The parking retarder shall conform to the European directive on machinery 2006/45 and its translation into national law of the country of deployment.	Conformity is required for commercial product, part of CE-conformity	-

ID	REQ Type	Object Text	Rationale	Status
5.4.2.3 Controller				
TRPR-30	functional	The controller shall be able to interface with several parking retarders.	Lower product costs	-
TRPR-31	functional	The controller shall be able to activate and deactivate the parking retarder.	Main function of controller	-
TRPR-32	functional	The controller shall supervise the state of the parking retarder by distinguishing at least between: active, inactive, alarm and failure.	Knowing the state of the parking retarder is essential for controlling it and for integration into superordinate systems	-
TRPR-33	functional	The controller shall supervise whether or not wagons are located within the parking retarder.	Required for activation	-
TRPR-34	functional	The controller shall evaluate the parking retarder to be in inactive state when the parking retarder is in a position to allow safe passage of rail vehicles.	Evaluation of inactive state	-
TRPR-35	functional	The controller shall evaluate the parking retarder to be in active state when the parking retarder is in a position to secure wagons against unintentional movements.	Evaluation of active state	-
TRPR-36	functional	The parking retarder shall observe wagon movements when the retarder is in active state.	Required for evaluation of alarm state	-
TRPR-37	functional	The controller shall evaluate the parking retarder to be in alarm state, if a movement of wagons is detected in active state.	Responsibles are informed when wagons are moved out of the retarder in active state. There may be a chance to take counter measures.	-
TRPR-38	functional	The controller shall evaluate the parking retarder to be in failure state, if no information regarding its state is available, e.g. relevant interfaces do not provide any signals.	Example: Connection line to wheel sensors or sensors within the retarder is interrupted.	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-39	functional	The controller shall evaluate the parking retarder to be in failure state when activation or deactivation cycles do not end in the designated final states.	Example: The retarder is secured in inactive state with locking bolts. Under a deactivation cycle, the retarder is deactivated but locking bolts for inactive state cannot be set into the final locking position.	-
TRPR-40	functional	Further conditions for the failure state can be specified with knowledge of the retarder design.	All possible cases can only be analysed with knowledge of the system architecture.	-
5.4.2.3.1 Activate parking retarder				
TRPR-41	functional	The request to activate the parking retarder shall be received from an external interface.	The command for the request is outside the system boundary	-
TRPR-42	functional	The request shall only be accepted if a wagon is located within the parking retarder, the current state is inactive and the lock in inactive state is not set.	Ensures that the retarder in active state means that it really holds a wagon (one axle). Otherwise, an activation does not make sense.	-
TRPR-43	functional	After a positive check, actuators of the parking retarder shall be controlled to activate it.	Activation of parking retarder as action	-
5.4.2.3.2 Deactivate parking retarder				
TRPR-44	functional	The request to deactivate the parking retarder shall be received from an external interface.	The command for the request is outside the system boundary	-
TRPR-45	functional	The request shall only be accepted if the current state is active or alarm.	In inactive state, no measures need to be taken. In failure state, the reasons for failure should be clarified first.	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-46	functional	After a positive check, actuators of the parking retarder shall be controlled to deactivate it.	Deactivation of parking retarder as action	-
5.4.2.3.3 Lock in inactive state				
TRPR-47	functional	The controller shall have a logical lock which ensures that commands to activate the parking retarder will not be executed.	If a train route is set, ending in or going through the track, not only has the parking retarder to be in inactive state, it also has to be ensured that no activation is done while the train route is active.	-
TRPR-48	functional	The request for the lock shall be received from an external interface.	The command for the request is outside the system boundary	-
TRPR-49	functional	The lock shall only be set when the parking retarder is in inactive state.	Precondition for lock	-
TRPR-50	functional	The lock shall only be deactivated if the corresponding request comes from the same post that requested the activation of the lock.	Only the post that needs the lock can determine when the lock is not needed any more. Otherwise, unsafe situation may occur.	-
5.4.2.3.4 Interfaces				
TRPR-51	functional	The controller shall provide at least two interfaces to superordinate systems.	See section 5.4.2.6	-
TRPR-52	functional	The physical layer of the interface shall consider the technological state of the superordinate systems.	Often, existing interlockings are relay based	-
5.4.2.4 RAMS				
TRPR-53	non-functional	The tolerable hazard rate for an unintentional deactivation of the parking retarder shall be less than $1e^{-6}$ 1/h.	Standard hazard rate for functions in yards	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-54	non-functional	The tolerable hazard rate for an unintentional activation of the parking retarder shall be less than 1e^{-6} 1/h.	Standard hazard rate for functions in yards	-
5.4.2.5 Option: Retarder signal				
	informative	This section describes an option which is especially relevant if the length of the parking retarder is chosen so that only specific stop position of the train allows activation of the retarder. The signal indicates the locomotive driver whether at least one wagon is located within the retarder.		-
TRPR-55	functional	The retarder signal shall be a visual indicator mounted on a pole.	Basic definition of retarder signal	-
TRPR-56	functional	The indicator shall be orientated towards the middle of the track.	The indicator needs to be visible for the driver.	-
TRPR-57	functional	The indicator shall be installed on the pole at a height of 3m.	The value of 3 m is approximately at the same level of the eyes of the driver.	-
TRPR-58	functional	The retarder signal should be installed on the right side of the track in the direction of travel.	The driver need to be able to assign a signal to a specific track unambiguously.	-
TRPR-59	functional	The indicator light shall only be switched on if the retarder is in inactive state and wagons are positioned in the track so that activation of the retarder is possible.	The indicator should not be visible at all times. It is sufficient when it is visible only in this particular circumstance. It could otherwise confuse drivers in adjacent tracks.	-
TRPR-60	functional	The retarder signal shall be installed 6m from the fouling points.	Existing signal poles can be reused.	-

ID	REQ Type	Object Text	Rationale	Status
TRPR-61	functional	If the track is typically entered from both sides, two retarder signals shall be installed.	The signal function is only helpful if visible regardless the direction of entry.	-
5.4.2.6 Extended requirements				
	informative	In this section, further recommendations regarding the integration of the system into superordinate systems are described depending on the use case. As the objective is outside the system boundaries, the description is informative only.		-
	informative	It is suggested, to realise two interfaces between the controller and superordinate systems: the mainline interlocking responsible for the entrance group and the yard automation system.		-
	informative	The state of the parking retarder should be transmitted to the yard automation system and the mainline interlocking.		-
	informative	Activation and deactivation commands of the parking retarder should be sent from the yard automation system.		-
	informative	Staff shall ensure that activation of the parking retarder in only done after standstill of the train in agreement with the loco driver.		-
	informative	The main line interlocking should have exclusive access to the function "Lock in inactive state".		-
	informative	When setting a train route into the entrance track, the interlocking should activate the function "lock in inactive state".		-
	informative	When releasing the train route, the lock should be deactivated.		-
	informative	Shunting routes should not be affected by the parking retarder.		-
	informative	If the hump yard is designed for automatic remote controlled humping locomotives, the yard automation system shall ensure that the parking retarder is in inactive state before starting the approach.		-

5.4.3 Decoupling in hump yards

This specification lists requirements for the development of solutions for decoupling of wagons equipped with DAC type 5. The solutions address especially the use case of hump shunting. Requirements are derived from section 5.2.1.1 and focus only concepts 2 and 8, as these are envisaged for realisation in task 12.2. In this specification, they are referred to as variant for lowly or highly automated yards, respectively. The situation of the transformation state, as defined by Deliverable 2.1, involving rollout of AC2, DAC 4, DAC 4.5 or any mixture with those wagons, is not considered. Furthermore, solutions for decoupling of wagons/wagon groups in the entrance group, are excluded as well.

Table 35: Specification list hump decoupling

ID	REQ Type	Object Text	Rationale	Status
Introduction				
	informative	This specification lists general requirements and specific requirements for two variants of solutions for decoupling in hump yards. The variants differ in the level of automation and consider different states of equipment in hump yards that can be found in Europe today. Operators can choose between the variants for a specific yard considering the required preconditions and cost-benefit aspects amongst others. See sections 5.4.3.3 and 5.4.3.4 for a more detailed description of the variants and their system boundaries.		-
5.4.3.1 Preconditions				
TRDC-1	functional	Solutions for decoupling in hump yards shall base on the DAC type 5, installed on the locomotive, used for humping, and all wagons of inbound trains.	DAC type 5 allows automated decoupling and is envisaged for target state.	-
TRDC-2	functional	Solutions for decoupling in hump yards shall base on train functions allowing to decouple wagons or wagon groups remotely	Train functions allow remote decoupling and are only	-

ID	REQ Type	Object Text	Rationale	Status
		via the DAC type 5. These train functions can be used via an interface to the Lead CCU, installed on the locomotive.	accessible via the locomotive.	
5.4.3.2 General requirements				
TRDC-3	functional	Solutions for decoupling of wagons shall be designed to decouple wagons or wagon groups in proximity of the hump.	Deactivating the prevent recoupling function with a wagon-autonomous time condition is only feasible if decoupling is done during hump shunting. When decoupling is done in the entrance group, the moment of separation on the hump is unpredictable.	-
TRDC-4	functional	A wagon or wagon group should not be decoupled when there are tensile forces between the coupler heads in question.	Depending on the value of tensile force, decoupling may lead to abrasive wear or may not be possible at all.	
TRDC-5	functional	The prevent recoupling function should be used to avoid recoupling of wagons between the moment of decoupling and separation of the wagons from the train on the hump.	Longitudinal vibrations may occur which can lead to an unintentional recoupling event.	
TRDC-6	functional	An autonomous time condition, implemented on the wagon CCUs, shall be used to set the coupler heads from the state “prevent recoupling” to “ready to couple”.	Simple and cost-effective approach, as only a standardised software feature is required.	
5.4.3.2.1 Cut list				
TRDC-7	functional	The cut list shall be provided by external systems to solutions for decoupling of wagons.	Required for decoupling of wagons in marshalling yards	

ID	REQ Type	Object Text	Rationale	Status
TRDC-8	functional	The cut list shall contain the sequence of wagons, the split points, the UIC wagon numbers and the total weights of each wagon.	Required for comparison with train composition, selection of split points and calculation of split positions.	
5.4.3.2.2 Acquire train composition and comparison with cut list				
TRDC-9	functional	Before the approach to the hump, solutions for decoupling of wagons should acquire the train composition from the Lead CCU.		
	informative	The train composition contains amongst others the sequence of wagons and for each wagon: the UIC wagon number, the number of axles, the length and the distribution of axles over the length of the wagon.		
TRDC-10	functional	The acquired train composition should be compared with the cut list before the approach to the hump.	The sequence of wagons and their identity, given by the cut list, should match with the train composition, acquired from the Lead CCU. Communication to parts of the train may be interrupted or the cut list may be erroneous.	
TRDC-11	functional	If there is a mismatch between the train composition and the cut list, staff shall decide about alternative options. The cut list has to be adapted in order to conform with the train composition.	Decoupling is only possible for wagons contained in the train composition.	
5.4.3.2.3 Check technical ability to decouple				
TRDC-12	functional	Solutions for decoupling of wagons should check the technical ability of the train to decouple wagons at given split points.	Even though a wagon is part of the train composition, its battery may not have a sufficient state of charge to drive the decoupling motor in	

ID	REQ Type	Object Text	Rationale	Status
			the coupler head or diagnostic information indicate that the decoupling mechanism in the coupler head is disturbed. Hence, decoupling during hump shunting will fail.	
TRDC-13	functional	If the result of the check indicates that decoupling at the envisaged split points is not possible, staff shall change the cut list by modifying split points or a manual sorting needs to take place before hump shunting.	Sorting can only be done at split points where decoupling is possible.	
5.4.3.2.4 Pre-selection of split points				
TRDC-14	functional	Split points, given by the cut list, shall be preselected for decoupling commands.	In the variant where decoupling is triggered by staff (variant for lowly automated yards), it reduces the activity during hump shunting.	
5.4.3.2.5 Estimate earliest and latest location of separation				
	informative	The track coordinate, where a wagon (group) would separate from the rest of the train in decoupled state, is the location where compressive forces turn into tensile forces. In this specification, this location is called actual location of separation. The track coordinate is related to the split point itself, i.e. the plane defined by both coupler front plates. The actual location of separation depends on several parameters that have to be considered. Examples for known parameters are: the track topology (length and gradient of track segments), individual axle loads of a wagon (group) to be decoupled, distances between axles of wagon (groups) to be decoupled. Examples for parameters that can only		

ID	REQ Type	Object Text	Rationale	Status
		be estimated are resistance forces of the wagons, influence of wind forces attacking at the wagon body. For the parameters, that can only be estimated, a best and a worst case can be estimated. Together with the known parameters, an earliest and latest location of separation can be estimated. The actual location of separation, where wagons will separate, is between the earliest and latest location of separation.		
TRDC-15	functional	Solutions for decoupling of wagons shall have a calculation model that estimates the earliest and latest location of separation for each wagon (group), that is decoupled from the train. This does not apply to variant for lowly automated yards.	Basis for selection of split positions	
5.4.3.2.6 Split position				
	informative	The split position is a target coordinate where the split point (plane defined by both coupler front plates) is located when the decoupling command should be triggered.		
TRDC-16	functional	The split position shall be chosen to be before the earliest location of separation.	The decoupling action must be finished at the earliest location of separation. Due to delays, the decoupling command must be triggered before.	
TRDC-17	functional	Solutions for decoupling of wagons shall determine the split position considering at least the travelled distance during the time span the coupler heads need to open.	Contributing delay.	
TRDC-18	functional	Solutions for decoupling of wagons shall determine the split position considering at least the travelled distance during the latency time from the acting component giving the decoupling command to the start of the decoupling action in the coupler heads.	Contributing delay.	

ID	REQ Type	Object Text	Rationale	Status
TRDC-19	functional	An additional margin may be useful depending on the grade of automation of the variant.	Staff in the loop that determine the current location of the split point, have typically longer reaction times and tend to locate in more imprecise manner.	
5.4.3.2.7 Determine time span to set coupler heads from "prevent recoupling" to "ready to couple"				
TRDC-20	functional	The time span shall at least consider the humping speed and the distance from the split position and latest location of separation.	For a reliable process, the prevent recoupling function has to be active until separation on the hump.	
TRDC-21	functional	An additional margin may be useful depending on the grade of automation of the variant.	Staff in the loop that determine the current location of the split point visually, have typically longer reaction times and tend to locate in more imprecise manner.	
TRDC-22	functional	The chosen time span shall not exceed the duration that a wagon (group) needs for the travel from the split position to the entrance of the classification track.	It is intended that wagons couple automatically in the classification track.	
5.4.3.2.8 Deactivate electric power supply				
TRDC-23	functional	Before the start of hump shunting, solutions for decoupling of wagons shall switch off the 400V/AC electric power supply.	If wagons are decoupled while electric current is running through the coupler heads, electric arcs may occur. These may damage the contacts in the electric part of the coupler heads.	

ID	REQ Type	Object Text	Rationale	Status
5.4.3.2.9 Deactivate parking brakes				
TRDC-24	functional	Before the start of hump shunting, solutions for decoupling of wagons shall deactivate the parking brakes of wagons if there are wagons in the train composition with active parking brakes.	Parking brakes may be used in the entrance group. For any movement, the parking brakes must be deactivated.	
5.4.3.2.10 Disable pneumatic brake				
TRDC-25	functional	Solutions for decoupling of wagons shall disable the pneumatic brake before wagons or wagon groups are decoupled from the train composition.	During sorting of the hump, wagons are required to have free running characteristics as they roll down the hump on their own driven by forces of gravity.	
5.4.3.2.11 Decoupling of wagons				
TRDC-26	functional	Solutions for decoupling of wagons shall send a decoupling command to the Lead CCU for a specific split point with the precalculated time span, used to reset the "prevent recoupling" state to "ready to couple" state.	The Lead CCU is the master controller on the train and thus the only instance that can control the decoupling function.	
TRDC-27	functional	Solutions for decoupling of wagons shall send the decoupling command for a specific split point when the split point is at its split position.	Decoupling command needs to be triggered at a defined time.	
5.4.3.3 Variant for lowly automated yard (concept 2)				
	informative	The variant is dedicated to hump yards with low or occasional traffic or to hump yards with older infrastructure equipment. It aims to provide a simple and cheap solution in the transformation process enabling a continuation of operation after the introduction of the DAC type 5. The variant can also be used for fly		

ID	REQ Type	Object Text	Rationale	Status
		shunting operation. A locomotive driver is required for driving the locomotive during approach and hump shunting. Decoupling of wagons is done remotely by a shunting assistant, equipped with a mobile device. The shunting assistant is either located on the hump or at another location with visibility (directly or via screens) to the hump. It is assumed that the cut list cannot be provided in digital manner, e.g. in paper form.		
5.4.3.3.1 Scope of solution				
TRDC-28	functional	The technical solution for decoupling of wagons in the variant for lowly automated yards shall consist of a mobile device with HMI and a software application, operated by the shunting assistant.	System definition of variant for lowly automated yards	
TRDC-29	functional	The technical solution for decoupling of wagons in the variant for lowly automated yards shall consist of a component onboard the locomotive providing an interface to the Lead CCU and a wireless interface to the mobile device. The component shall enable necessary communication between the mobile device and the Lead CCU.	System definition of variant for lowly automated yards	
TRDC-30	functional	The technical solution for decoupling of wagons in the variant for lowly automated yards shall include a communication network allowing wireless communication between mobile devices and named component on the locomotives.	System definition of variant for lowly automated yards	
5.4.3.3.2 Functional requirements				
TRDC-31	functional	The mobile device shall send a request to the Lead CCU to acquire the train composition.	Assignment of function 'comparison between train composition and cut list' in variant for lowly automated yards to stakeholders/components	

ID	REQ Type	Object Text	Rationale	Status
TRDC-32	functional	The shunting assistant shall trigger the request to acquire the train composition via the HMI.	Assignment of function 'comparison between train composition and cut list' in variant for lowly automated yards to stakeholders/components	
TRDC-33	functional	The mobile device shall display the acquired train composition on the HMI.	Assignment of function 'comparison between train composition and cut list' in variant for lowly automated yards to stakeholders/components	
TRDC-34	functional	The shunting assistant shall compare the cut list with the train composition.	Assignment of function 'comparison between train composition and cut list' in variant for lowly automated yards to stakeholders/components	
TRDC-35	functional	The mobile device shall offer the possibility to set split points in the train composition, acquired from the Lead CCU.	Assignment of function 'Pre-selection of split points' in variant for lowly automated yards to stakeholders/components	
TRDC-36	functional	The shunting assistant shall set the split points according to the cut list via the HMI on the mobile device.	Assignment of function 'Pre-selection of split points' in variant for lowly automated yards to stakeholders/components	

ID	REQ Type	Object Text	Rationale	Status
TRDC-37	functional	The mobile device shall check whether decoupling at selected split points is technically possible.	Assignment of function 'Check ability to decouple' in variant for lowly automated yards to stakeholders/components	
TRDC-38	functional	The mobile device shall display the state of parking brakes if wagons are equipped with parking brakes.	Assignment of function 'Deactivate parking brakes' in variant for lowly automated yards to stakeholders/components	
TRDC-39	functional	The mobile device shall be able to send a request to the Lead CCU to deactivate all parking brakes.	Assignment of function 'Deactivate parking brakes' in variant for lowly automated yards to stakeholders/components	
TRDC-40	functional	The shunting assistant shall trigger the request to deactivate all parking brakes, if any parking brake is active.	Assignment of function 'Deactivate parking brakes' in variant for lowly automated yards to stakeholders/components	
TRDC-41	functional	The mobile device shall display the state of the 400 V/AC power line.	Assignment of function 'Deactivate electric power supply' in variant for lowly automated yards to stakeholders/components	
TRDC-42	functional	The mobile device shall be able to send a request to the Lead CCU to deactivate the 400 V/AC power line.	Assignment of function 'Deactivate electric power supply' in variant for lowly automated yards to	

ID	REQ Type	Object Text	Rationale	Status
			stakeholders/components	
TRDC-43	functional	The shunting assistant shall trigger the request to deactivate the 400 V/AC powerline.	Assignment of function 'Deactivate electric power supply' in variant for lowly automated yards to stakeholders/components	
TRDC-44	functional	The mobile device shall offer the possibility to set a default time span for all split points, used to set coupler heads from "prevent recoupling" to "ready to couple", via the HMI.	Assignment of function 'Determine time span to set coupler heads from "prevent recoupling" to "ready to couple' in variant for lowly automated yards to stakeholders/components	
TRDC-45	functional	Alternatively, the mobile device shall also offer the possibility to select individual time spans for each split point.	Depending on the length of the cut, the acceleration of cuts varies. Very long cuts require longer time spans.	
TRDC-46	functional	The shunting assistant shall select the time span to set coupler heads from "prevent recoupling" to "ready to couple" via the HMI.	Assignment of function 'Determine time span to set coupler heads from "prevent recoupling" to "ready to couple' in variant for lowly automated yards to stakeholders/components	
TRDC-47	functional	The mobile device shall send decoupling commands for a specific split point with the corresponding time span to the Lead CCU.	Assignment of function 'Decoupling of wagons' in variant for lowly automated yards to	

ID	REQ Type	Object Text	Rationale	Status
			stakeholders/components	
TRDC-48	functional	The shunting assistant shall estimate the split position for each wagon (group) during the hump shunting by visual means. The shunting assistant shall consider for the choice of the split position that the coupler heads in question are not yet under tensile forces.	Assignment of function 'Determine split position' in variant for lowly automated yards to stakeholders/components	
TRDC-49	functional	The shunting assistant shall determine by visual means when the split point is at the estimated split position and trigger the corresponding decoupling command via the HMI.	Assignment of function 'Decoupling of wagons' in variant for lowly automated yards to stakeholders/components	
5.4.3.4 Variant for highly automated yards (Concept 8)				
	informative	The variant is dedicated to hump yards with high traffic controlled by an electronic yard automation system. It is an automatic decoupling variant, located on the infrastructure side.		
5.4.3.4.1 Scope of solution				
TRDC-50	functional	The technical solution for decoupling of wagons in the variant for highly automated yards shall consist of software applications, installed on controllers of the yard automation system.	System definition of variant for highly automated yards	
TRDC-51	functional	The technical solution for decoupling of wagons in the variant for highly automated yards shall consist of a component onboard the locomotive providing an interface to the Lead CCU and a wireless interface to the yard automation system. The component shall enable necessary communication between the yard automation system and the Lead CCU.	System definition of variant for highly automated yards	
TRDC-52	functional	The technical solution for decoupling of wagons in the variant for highly automated yards shall include a communication network	System definition of variant for highly automated yards	

ID	REQ Type	Object Text	Rationale	Status
		allowing wireless communication between the yard automation system and named component on the locomotives.		
TRDC-53	functional	The yard automation system shall host an up-to-date version of the track topology model.	Preconditions of variant for highly automated yards	
TRDC-54	functional	The yard automation system shall have an interface to a dispatching system that provides the cut list in digital form including the sequence of wagons, the split points, the UIC wagon numbers and total weights for each wagon.	System definition of variant for highly automated yards	
5.4.3.4.2 Functional requirements				
TRDC-55	functional	The yard manager shall trigger the yard automation system to prepare hump shunting for a defined train, locomotive and hump track.	Interaction by operator required for yard automation system to start automated preparation procedure.	
	informative	The preparation includes the following functions:		
TRDC-56	functional	The yard automation system shall acquire the cut list for the inbound train (incl. Wagon loads) from the dispatching system.	Assignment of function 'comparison between train composition and cut list' in variant for highly automated yards to stakeholders/components	
TRDC-57	functional	The yard automation system shall send a request to the Lead CCU to acquire the train composition.	Assignment of function 'comparison between train composition and cut list' in variant for highly automated yards to stakeholders/components	
TRDC-58	functional	The hump control system shall compare the cut list with the train composition.	Assignment of function 'comparison between train	

ID	REQ Type	Object Text	Rationale	Status
			composition and cut list' in variant for highly automated yards to stakeholders/components	
TRDC-59	functional	The yard automation system shall check whether decoupling at split points, indicated by the cut list, is technically possible.	Assignment of function 'Check ability to decouple' in variant for highly automated yards to stakeholders/components	
TRDC-60	functional	The yard automation system shall preselect the split points in the train composition, provided by the cut list.	Assignment of function 'Pre-selection of split points' in variant for highly automated yards to stakeholders/components	
TRDC-61	functional	The yard automation system shall send a request to the Lead CCU to deactivate all parking brakes if any parking brake is active.	Assignment of function 'Deactivate parking brakes' in variant for highly automated yards to stakeholders/components	
TRDC-62	functional	The yard automation system shall send a request to the Lead CCU to deactivate the 400 V/AC power supply if the powerline is active.	Assignment of function 'Deactivate electric power supply' in variant for highly automated yards to stakeholders/components	
TRDC-63	functional	The yard automation system shall inform the yard manager about the process of preparation and the results via its operating and control system.	Interaction by operator required in case of failures/mismatches such as adapting the cut list but also for feedback to start hump	

ID	REQ Type	Object Text	Rationale	Status
			shunting	
TRDC-64	functional	The yard manager shall start hump shunting when preparation has finished and the route to the defined hump track has been set by the interlocking.	The yard automation system needs a command for starting the hump shunting	
TRDC-65	functional	The yard automation system shall determine the earliest and latest location of separation based on a calculation model, introduced by TRDC-15.	Assignment of function 'Estimation of earliest and latest location of separation' in variant for highly automated yards to stakeholders/components	
TRDC-66	functional	The yard automation system shall determine the split position for each split point individually based on requirements TRDC-16, TRDC-17, TRDC-18 and TRDC-19.	Assignment of function 'Determine split position' in variant for highly automated yards to stakeholders/components	
TRDC-67	functional	The yard automation system shall calculate the time span for setting the coupler heads from prevent recoupling into ready-to-couple considering the humping speed and the distance between the split position and the latest location of separation.	Assignment of function 'Determine time span to set coupler heads from "prevent recoupling" to "ready to couple" in variant for highly automated yards to stakeholders/components	
TRDC-68	functional	During humping shunting, the yard automation system shall track the current locations of all split points either by evaluating the received position reports of the locomotive or by using sensors on the hump tracking the train front end.	Assignment of function 'Decoupling of wagons' in variant for highly automated yards to stakeholders/components	
TRDC-69	functional	When the first/subsequent/last split point reaches its split	Assignment of function	

ID	REQ Type	Object Text	Rationale	Status
		position, the yard automation system shall trigger the decoupling command.	'Decoupling of wagons' in variant for highly automated yards to stakeholders/components	
TRDC-70	functional	The yard automation system shall send a decoupling command together with information on the split point and the calculated timespan to the Lead CCU.	Assignment of function 'Decoupling of wagons' in variant for highly automated yards to stakeholders/components	
5.4.3.5 Components				
	informative	This section lists requirements for components that are part of solutions for decoupling.		
5.4.3.5.1 Mobile device				
TRDC-71	functional	The mobile device shall have a human machine interface (HMI) displaying information and allowing user inputs.	The mobile device is operated by a human being. Both display of information and user inputs are required.	
TRDC-72	functional	The mobile device shall operate on battery power.	The device is not mobile if wired to a charging point.	
TRDC-73	functional	The mobile device shall be designed with a minimum protection class of IP 64 according to EN 60529.	Outdoor conditions can include rain.	
TRDC-74	functional	The mobile device shall have a wireless interface.	Interfaces such a Wifi/LTE/5G required for communication	
TRDC-75	functional	The software application on the mobile device shall be able to establish a connection to the communication network.	Information on how to connect with the communication network needs to be available on the mobile device, e.g.	

ID	REQ Type	Object Text	Rationale	Status
			hostnames/ports.	
5.4.3.5.2 Component on board the locomotive				
TRDC-76	functional	The component shall operate the interface with the Lead CCU and the wireless interface to components on the infrastructure side.	Definition of surrounding components	
TRDC-77	functional	The component shall be able to establish a wireless connection to the communication network.	Information on how to connect with the communication network needs to be available on the component	
TRDC-78	functional	The component shall forward telegrams received from the infrastructure side to the Lead CCU and vice versa. If different formats or protocols are used, a conversion of telegrams is required.	Main purpose of component	
5.4.3.6 Interfaces				
	informative	This chapter lists requirements for design of the interfaces.		
5.4.3.6.1 General requirements				
TRDC-79	functional	Data, exchanged via the interfaces, shall be checked for completeness and integrity.	The meaning of received telegrams can change completely if parts are missing or erroneous.	
TRDC-80	functional	Interfaces shall be designed so that the sending component can always verify that the receiving component has received telegrams.	Unreliable communication, e.g. UDP does not fulfil this requirement	
TRDC-81	functional	If feasible, receiving components should send replying telegrams to requests.	Replying messages can contain data upon requests or acknowledgments/rejects.	
TRDC-82	functional	The physical and logical interface between the Lead CCU and component on the infrastructure side (mobile device or yard	A Europe-wide standardisation reduces product costs and	

ID	REQ Type	Object Text	Rationale	Status
		automation system) shall be defined and standardised.	ensures the modular approach of the variants.	
5.4.3.6.2 Communication infrastructure and wireless interface between component on board the locomotive and mobile device/yard automation system				
TRDC-83	Non-functional	The interface shall be protected with state-of-the-art measures for IT-security.	Intruders may try to disturb or corrupt communication.	
TRDC-84	Non-functional	A monitoring process shall be established ensuring that IT-security measures are kept up to date during the operating lifetime of the interface.	Security gaps can be identified after installation. Security patches then need to be installed in order to close gaps, not prior known.	
TRDC-85	Non-functional	Components using the interface shall be required to authenticate.	Only telegrams by entitled components must be respected in order to forbid intruders to capture control of systems.	
TRDC-86	Non-functional	Availability of the wireless interface shall be ensured in the entrance group and the hump area of the yard.	Occupancy of tracks by other trains, weather conditions or obstacles by building infrastructure such as bridges shall not lead to gaps in connectivity.	
TRDC-87	functional	The logical interface may use the same physical interface as solutions for automatic shunting. In that case, the interface shall be working independently.	Modular approach for decoupling and automatic driving	
5.4.3.6.3 Interface between Lead CCU and component on board the locomotive				
TRDC-88	functional	The interface between Lead CCU and the component on board the locomotive shall be wired.	A wired interface has a higher availability and is sufficient for	

ID	REQ Type	Object Text	Rationale	Status
			communication between two nodes on the same vehicle.	
	informative	IT-Security measures are not required as both nodes of the wired interface are located on the locomotive that is assumed to be inaccessible by intruders.		

5.4.4 Requirements Yard Management System

For this purpose, the basic necessary atomic functionalities must be available in the YMS, such as commands for (de)coupling, receiving information regarding the train consists, number of wagons, length, the calculation and specification of shunting missions (A -> B, speed), etc.

These functionalities and the available information can then be used by an operator and/or by the YMS for the generation and implementation of more complex tasks and shunting missions to fulfil the planned and necessary activities.

Table 36: Requirements Yard Management System

ID	REQ Type	Object Text	Rationale	Status
UI etc.				
YMS-010	functional	The YMS shall provide a graphical user interface to visualize the yard and send commands to and get feedback from connected systems (according to specific interface specifications).		-
YMS-020	functional	The YMS shall visualize the whole track layout and the occupation with traction units and train consists.		-
YMs-030	functional	The YMS shall track and visualize the position of traction units and train consists on the track layout. The lengths of wagons shall be taken into account to calculate the length of consists.		-
YMS-040	functional	The YMS shall be able to visualize the actual status of traction units and train consists (coupled, prevent coupling status of couplers, dangerous goods, battery status, brake status etc.).		
YMS-050	functional	The YMS shall visualize the state of the infrastructure (points, signals and shunting routes) in the yard.		-
YMS-060	functional	The YMS should be able to calculate routes based on the current situation of the status in the yard (occupancies of tracks, blocking of tracks, defect switches etc.)		
	non functional	The YMS shall be usable on standard workstation computers as well as on mobile devices (YMS		-

		mobile).		
	non functional	The YMS shall be based on a system that is scalable depending on the size of the yard, required functionalities, number of users, number of connected external systems, required performance etc.		-
	non functional	The YMS shall be able to be included in the overall required IT security architecture.		-
User Management				
YMS-070	functional	The YMS shall support a sophisticated authorization concept including multiple users, roles and authorizations.		-
Interfaces				
YMS-080	functional	The YMS shall have interfaces to the following systems: ASO system, Brake test system(s), Video gate system(s), Yard Automation System, Interlocking system(s), Yard Planning System, Train Announcing System etc,		
YMS-090	functional	The YMS shall be able to handle planning data received manually or from a planning system like train numbers, track information, arrival, departure, traction unit (at arrival, while shunting, at departure), consist compositions, cut lists, required shunting movements, special handlings, dangerous goods, etc.)		
YMS-100	functional	The YMS shall visualize the connection state to all external systems. Broken connections shall be clearly indicated to catch the attention of the operator.		-
Interface to Yard Automation System (YAS)				
YMS-110	functional	The YMS shall get information from the YAS regarding its current status of the hump interlocking		-
YMS-120	functional	The YMS shall supply information to the YAS regarding the traction unit, consist composition, cut list- etc.		-
YMS-130	functional	In a hump yard the YMS shall be able to initiate the hump shunting		-

		sequence in communication with the YAS		
YMS-140	functional	The YMS shall get the status of hump sequences (Started, Current state, Finished, etc.) immediately on status change.		-
Interface to Interlocking Systems (not yard automation system)				
YMS-150	functional	The YMS shall get information from other interlocking systems regarding failure states, track occupancy, state of switches, signals, level crossings, etc.		-
Interface to ASO trackside				
YMS-160	functional	The YMS shall be able to register and deregister for communication with traction units (mainline as well as shunting locomotives)		-
YMS-170	functional	The YMS shall get information about the current state of traction units (consist composition, wagon numbers, length, weights, battery states, DAC states)		-
YMS-180	functional	The YMS shall get information about the position of traction units		-
YMS-190	functional	The YMS shall be able to supply shunting missions based on self calculated routes to traction units (start and target, velocity, etc.)		-
YMS-200	functional	The YMS shall supply coupling / uncoupling / prevent coupling mode (for DACs) commands to traction units		-
Archiving / Reports				
YMS-210	functional	The YMS shall archive operating actions, movements of tractions units, train consists, state changes of the infrastructure and external systems etc.		-
YMS-220	functional	The data in the archive shall only be accessible by specific roles in the system.		-
YMS-230	functional	The YMS shall be able to pseudonymize, anonymize and delete data in the archive after a certain period of time.		-
YMS-240	functional	The YMS shall be able to export archive data for further analyses		-

		and visualization by external systems.		

5.5 Catalogue of Technical Requirements for ASO

5.5.1 ASO general

The European Railways are currently in the process of implementing ETCS. The railways have identified an opportunity to achieve improved capacity, on-time performance and make energy efficiency improvements through developing and implementing Automatic Train Operation (ATO). ERTMS/ATO is the system of systems which performs some or all of the functions of automatic speed regulation, accurate stopping, door opening and closing, performance level regulation, reaction to incidents (GoA3 and GoA4), and other functions assigned to a train driver or train attendant.

However, when it is about freight logistics, European Railways not only operate trains, but also do a lot of wagon processing for sorting wagons as well as for the pickup and delivery of wagons as direct procedural interfaces to the customer.

Regarding Full Digital Freight Train Operation (FDFTO) as it is worked out in ER-JU`s FP5, the subproject Yard has focussed on wagon processing and therefore looked into the requirements for ASO (Automated Shunting Operation) in context with the DAC (Digital Automated Coupler) as an enabler.

The GoA levels defined in IEC62290-1 are derived from operation of passenger trains or even metros, in any case focussed on “train operation”, not considering the requirements of single wagon operations, let alone with logistic chains where Rail is involved and which is in the focus of FDFTO. But even looking at GoA levels from freight train operations perspective as such, the need to differentiate from passenger services seems obvious. There simply are no passengers getting on/off the train, herewith no automated open/close door function needed as well as regularly no on-board staff present.Therefore, FP5 SP Yard has worked out an extended version of GoA levels to be discussed with system pillar for further approvals.

From a use case perspective and when looking into the intermediate and target processes defined in FP5 FDFTO it seems clear that for shunting (wagon processing) it either needs additional Operational Requirements (in target process at the latest), or shunting (wagon processing) is considered as a kind of “degraded” mode (FDFTO shunting mode).

While ATO and TMS work together to maintain a train within a defined tolerance of the operational timetable whilst managing conflicts to ensure that overall train operation is optimized, ASO and YAMS / Yard Planner System work together to carry out shunting orders within a designated ASO area with a sequence of movements, potentially supported by AI for optimization.

Since ASO contains components of remote control it is a safety critical system.

In this document ASO is used as an abbreviation for Automated Shunting Operation.

While interoperability is a clear goal of FP5 FDFTO, it goes without saying that train functions of FDFTO train run mode have to be harmonized with ATO. At the same time FDFTO shunting mode has to be considered, as in this mode the train “disappears”. Only a traction unit (TU) can be addressed, with ever changing wagon compositions after every single movement. Still exact positioning of every single or group of wagon has to be tracked and documented. So, the summarized goals here can only apply to the TU. Still, it makes sense in case of addressing DAC as enabler for FDFTO to introduce an ASO scheme for s, corresponding with FDFTO shunting mode. Otherwise, GoA-levels could only become applicable with FDFTO train run at all.

All subsystems of ASO shall be interoperable, independent of the supplier. In order to achieve interoperability within a given grade of automation, the on-board and infrastructure equipment shall take into account the goals summarised below.

The architecture should be ready for each GoA but the specific implementation should take into account the automation level of the yard in order to avoid unnecessary costs.

The ASO system shall comply with the following performance parameters, which shall be specified for each application by the Railways.

- Maximum speed;
- Headway;
- Stopping accuracy;
- Required reaction times;

During ASO operation, it shall be possible to supervise TU location by monitoring TUs automatically using unique identification and status to recognise deviations from normal operation as soon as possible.

During ASO operation the location of all TU and wagons must be supervised in the Yard.

During ASO operation, it shall be possible to input the mission from the planning systems and to start the mission.

External systems and ATP shall ensure the safety of the consists, including the safe route, safe separation of consists, safe speed, authorisation of TU movements and safe stopping (including roll-away prevention) according to European rules and processes. For GoA2, The ASO system shall only be operational if all these safety pre-conditions are continuously met. Otherwise, the driver is responsible for the limited operation.

The ASO system shall be able to detect and react to obstacles and potential hazards on the route or in the physical environment thanks to a combination of different onboard and trackside solutions.

ASO shall support:

- Start and end of operation at any planned location,
- Preparation and awakening of DAC wagons and ASO, including a self-check, prior to setting the TU in operation;
- Starting in the appropriate GoA with or without manual intervention after awakening;
- Deactivating the ATO on-board by on-board or trackside command.
- the start and end of shunting operations within a yard
- the awakening of a single wagon or wagon group
- the awakening and deactivating of the ASO of a TU itself

New mission data required for ASO shall be entered only at standstill and then be distributed to the relevant TU and infrastructure systems as required to support the grade of automation.

The data entry is either a manual process, or possibly supported by automatic processes.

ASO shall support transitions between different grades of automation.

It shall be possible to change the driving direction either automatically or with the support of a TU operator.

ASO shall support the coupling and decoupling either automatically or with the support of a TU operator, in any case in FDFTO shunting mode only.

ASO shall display to the TU operator all information relevant for the current mission.

The YAMS/YMSmobile shall display to the driver and assistant the sequence of shunting activities planned, requested, authorized and currently executed under ASO

During ASO operation, it shall be possible to remotely operate the TU using a portable control device or from a remote driving centre.

Remote operation can be used at any time and in all yards where YAMS or YMSmobile is available.

In FDFTO shunting mode ASO will be performed remotely up to GoA4 by YAMS or YMSmobile.

The ASO system shall be able to align with external freight handling systems for loading or unloading (this will happen through the proper mission defined by the YAMS or YMSmobile).

Depending on the technical level of the interlocking/signalling system the ASO system after initialization shall be able to carry out a sequence of movements and (un)coupling activities without any active support of the driver but in connection with the YAMS (Shunting movements = missions).

The ASO use cases and operational scenarios are not suitable for GoA1 and GoA2 scenarios. At the same time, it seems obvious that GoA3/4 levels, as defined in IEC62290-1 for train runs, are for several reasons not in the same way applicable in FDFTO shunting mode and all related activities, although some of them refer to ER-JU FDFT "train functions".

ASO moves a traction unit, in most cases with a wagon set, forming a shunting composition, in FDFTO shunting mode, but not in train run mode; ASO moves a traction unit in a strictly defined area of a Yard; preferably with an ESR; ASO thus communicating with different interlocking systems. But ASO system can also work in isolation, supported by perception and positioning systems.

Both ETCS and ATO as well as ASO include on-board and trackside constituents. ETCS supervises the train ensuring that speed and movement limits are observed and the train proceeds only when it is allowed by the trackside to do so. The ATO on-board automatically drives trains, through control of traction and braking, including but not limited to accurate stopping at specified stopping positions using operational data provided by a traffic management system (TMS) and infrastructure data provided by trackside equipment.

ASO uses infrastructural as well as operational data provided by a Yard Management System (YAMS) or a Yard Manager and additional infrastructure data provided by digital mapping. The ASO on-board automatically drives a TU following a shunting order turned into a series of shunting movement (missions), through control of traction and braking, including accurate stopping for change of direction as well as for approaching and (de)coupling wagons.

Under ATO, Remote Operation is used during the following circumstances:

- Emergency situations;
- Degraded ATO mode;
- Inside yards, depots or stabling areas.

ASO shall automate shunting operation during FDFTO shunting mode inside yards and towards customer sidings (Last mile).

The ATO trackside interfaces with the Traffic Management System (TMS) which can automate normal signaller operations such as route setting and train regulation.

The ASO trackside interfaces with the Yard Management System (YAMS) which can automate the movement sequences for wagon processing, pickup or delivery. In defined areas the YAMS or the TU operator can also take over signaller operations such as turning switches and route setting.

ATO and TMS work together to maintain a train within a defined tolerance of the operational timetable whilst managing conflicts to ensure that overall train operation is optimized.

ASO and YAMS work together to carry out shunting orders within a defined area with a sequence of shunting movements (= missions), potentially supported by AI for optimization.

ASO shall be able to work with Electronic Shunting Path Requests (ESR).

Trackside constituents do not necessarily mean physical installations alongside track but can also mean radio based or other solutions (for positioning etc.) as well as the YAMS itself.

The ASO on-board automatically drives the TU, through control of traction and braking, with defined speed limits and movement distances, changes directions and decouples wagons at planned, calculated, defined stopping positions, using operational and infrastructure data provided by a Yard Management System (YAMS).

ASO and YAMS work together to carry out sequences of shunting movements (= missions) thus producing wagon transfers, (further on managing conflicts to ensure that overall shunting operation is optimised).

In the context of this specification, GoA1 (FDFT shunting mode) refers to manual driving with TU operator, nonautomated TU operation. The TU is driven manually or remotely by a shunting driver; not necessarily protected by automatic train protection (ATP). This GoA includes providing all shunting order information (movements, positions, decoupling, etc.) to assist manual driving. Decoupling can be done remotely (DAC5).

GoA2 (FDFT shunting mode) Semiautomated TU operation: The loco is driven automatically, stopping is automated but a TU operator (in the cab or remotely) is required to start automatic driving; the TU operator can check the track ahead is clear (optionally with technical support) and carry out other manual functions (operate switches, secure level crossings, etc.). The TU operator can take over in emergency or degraded situations.

GoA3 (FDFT shunting mode) Driverless TU operation The TU is operated automatically including automatic change of directions (= reverse departure), a shunting manager has some operational tasks (e.g., manual switching of points, operating the doors of industrial plants, technical wagon checks) and can assume control in case of emergency or degraded situations.

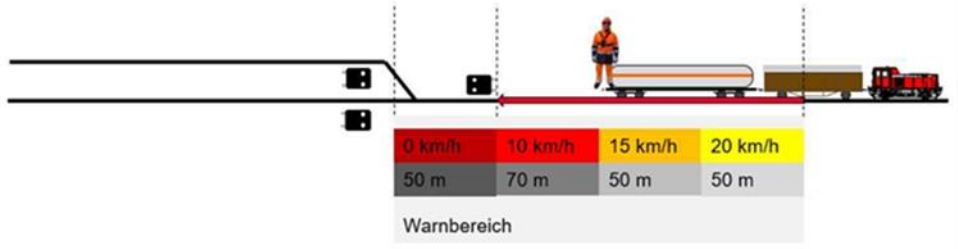
GoA4 (FDFT shunting mode) Unattended TU operation: No staff on-board required to operate the TU. All functions of shunting operation including decoupling are automated (DAC5) with no staff on-board to assume control in case of emergencies or degraded situations. Even if this GoA4 can be achieved for movement of consists, it will not cover all required FDFTO train functions or operational tasks as listed under GoA3.

5.5.2 ASO Operational Requirements

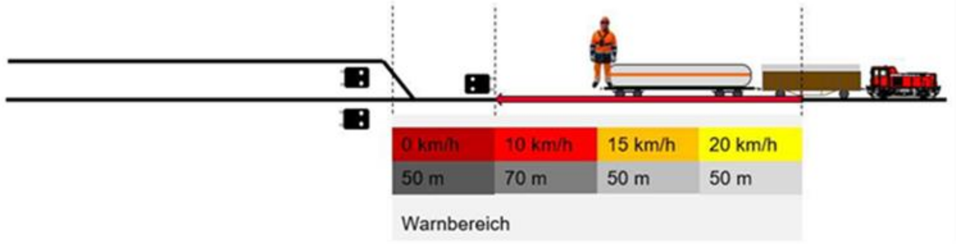
All requirements mentioned in this paper can be found in POLARION and will undergo the procedure foreseen in the FP5 requirement management. Nevertheless, as there is still some open topics on train functions and related architectures a continued interaction and flexibility from Yard perspective in relation to Flagship project Engineering will be necessary.

Table 37: ASO Functional Requirements

ID	REQ Type	Object Type	Rationale	Status
ASO-OR001	functional	The ASO on-board function and the ASO trackside function shall be interoperable		
ASO-OR002	functional	The ASO on-board shall be compliant with all of the ASO Operational Requirements for the GoAs operated.		
ASO-OR003	functional	The ASO on-board can be equipped for any GoA or combination of GoAs. Implementing a GoA shall not mandate implementing lower GoAs.		
ASO-OR004	functional	Any interoperable interfaces shall be compliant with all of the ASO Operational Requirements for the supported GoAs.		
ASO-OR005	functional	The ASO function (FDFT shunting mode) shall support a seamless handover between adjacent ASO tracksides.		
ASO-OR006	functional	The ASO trackside shall support data exchange with YAMS (Yard planning, dispatching, operation systems dedicated to shunting operations). General Principle 3: Interoperability with different grades of automation.		
ASO-OR007	functional	It shall always be possible to operate in the highest Grade of Automation supported by both the ASO trackside and the ASO on-board. General Principle 4: Interchangeability.		
ASO-OR008	functional	The ASO system should be able to work even when modifications of track layout and trackside or rolling stock performance are applied.		
ASO-	functio	The ASO on-board and the ASO trackside shall operate the highest system		

OR009	nal	version supported by both. Backward compatibility shall be possible by allowing the ASO on-board and the ASO trackside to support several system versions. General Principle 5: Backward compatibility.		
ASO-OR010	functional	The ASO function is a safety critical system. Any safety functionality required for the ASO to operate automatically shall be supervised via DMI and can be supervised by other safety systems. General Principle 6: Safety.		
ASO-OR011	functional	The ASO function shall achieve the specified requirements for interoperability.		
ASO-OR012	functional	The ASO trackside function (YAMS) shall be able to turn shunting orders into shunting missions out of operational (TAF-TSI) and infrastructure data.		
ASO-OR013	functional	The ASO trackside function shall send missions to the ASO on-board function.		
ASO-OR014	functional	The ASO on-board function shall stop the train where required at all defined reversing and (de)coupling Points between Shunting Missions  **Figure 61: ASO on-board function stop the train where required**		
ASO-OR015	functional	The ASO function shall support traction unit operating across a defined range of adhesion.		
ASO-OR016	functional	The available wheel – rail adhesion shall be taken into account by the ASO on-board function.		

ASO-OR017	functional	The ASO on-board function shall decouple wagons where required at defined Stopping Points between missions.		
ASO-OR018	functional	The ASO on-board function shall inform the ASO trackside in real time when changes of the wagon composition are detected according to the mission (train function: detect wagon composition and length)		
ASO-OR019	functional	The ASO trackside function shall regulate TU speed in a way that the wagon group attached is always considered in terms of length and weight.		
ASO-OR020	functional	The ASO on-board function shall be online (remote) controlled (via mobile device) to ensure its traction, coast and brake commands are adapted to the attached wagons to enable control of the vehicle to meet the defined shunting movements.		
ASO-OR021	functional	The ASO on-board function shall meet the shunting mission within distances given by ASO trackside and within the Electronic Shunting Path Request (ESR).		
ASO-OR022	functional	The ASO on-board function shall report its position to the ASO trackside.		
ASO-OR023	functional	The shunting mission distance shall use meters/centimeters (m/cm).		
ASO-OR024	functional	It shall be possible to assign specific missions to specific ASO activities (Pickup, Delivery, train formation).		
ASO-OR025	functional	A shunting mission shall include defined ("static") speed limits along requested shunting paths and on occupied tracks.		

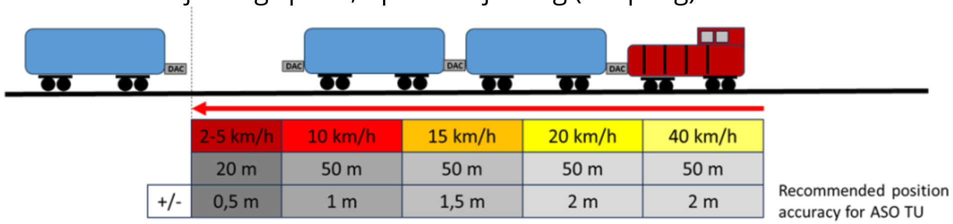
		 **Figure 62: shunting mission defined speed**		
ASO-OR026	functional	It shall be possible in the shunting mission to approach wagons for coupling (variable stopping points).		
ASO-OR027	functional	The ASO on-board function shall accept a valid shunting mission sent by the ASO trackside function.		
ASO-OR028	functional	An ASO TU shall be uniquely identified for a shunting order and all related shunting missions.		
ASO-OR029	functional	At any time if the ASO on-board function cannot comply with the distances, positions or (de)coupling points, the ASO trackside will generate an alert.		
ASO-OR030	functional	Upon receipt of the estimated deviation for reaching the next (De) Coupling or Reversing Points from the ASO onboard function, the ASO trackside function shall be able to send an updated shunting mission.		
ASO-OR031	functional	The ASO function shall support cancelling a mission automatically when a new shunting mission is assigned.		
ASO-OR032	functional	If the shunting mission is not achievable the ASO trackside should reject it.		
ASO-OR033	functional	If the infrastructure data from the shunting mission is not consistent with the infrastructure encountered, then the ASO shall disengage, until a consistent shunting mission is received.		

ASO-OR034	functional	The ASO on-board function shall support any changes to the intended final destination of the shunting mission before starting but NOT during the shunting movement.		
ASO-OR035	functional	The ASO on-board function shall support any changes to the intended routing before starting but NOT during the shunting movement (mission/journey).		
ASO-OR036	functional	The ASO on-board function shall support detection of all changes of consists (i.e. FDFT train function: composition detection) at any time during the shunting order (missions).		
ASO-OR037	functional	ASO and non-ASO traction units shall be able to operate in the same yard at the same time. This is valid ONLY under the assumption that all traction units are following the movement authorities granted at YAMS level.		
ASO-OR038	functional	When an ASO TU leaves an ASO trackside area the ASO on-board function is still able to detect and report its position (the ASO must include a positioning system).		
ASO-OR039	functional	De-activating or activating the ASO (FDFT shunting mode) onboard function shall be possible by a command from the (shunting) operator of the TU or the YAMS.		
ASO-OR040	functional	When the ASO on-board function is energised (FDFT Shunting mode), it shall be possible to assign a new mission to the ASO.		
ASO-OR041	functional	The ASO on-board function shall acquire shunting order/ shunting missions sequence data from the YAMS as an external source, thus supporting remote control.		
ASO-OR042	functional	It shall be possible to transmit train data from the YAMS (Yard planner, dispatching, operation) to the ASO onboard function and vice versa.		
ASO-OR043	functional	ASO TUs shall be authorised to depart from a Stopping Point, at the start of a shunting order or while carrying out consecutive shunting missions when all of the following conditions are met: • The wagon set is not immobilised by emergency braking or service braking		

		by a safe system. • The start of the TU is not inhibited by the ASO trackside function. • The TU is not held for traffic regulation purposes. • The TU is assigned a valid shunting order with valid Shunting missions. • Wagon set with all planned wagons is coupled to the TU and a split list is available. • Wagons are closed (after unloading/loading in case of pickup) • Wagons are technically secure for moving.		
ASO-OR044	functional	When all applicable conditions are met for the authorisation of the ASO TU, the ASO on-board function shall start automatic driving of the TU following a command executed by the TU operator or the YAMS(app).		
ASO-OR045	functional	The ASO on-board function shall command traction and brakes of the rolling stock in order to comply with the ASO Operational mission distance and the jerk rate limits.		
ASO-OR046	functional	The ASO on-board function shall ensure the requirements of the air brakes are met before applying traction/braking commands.		
ASO-OR047	functional	For ASO-TUs, it shall be possible to delay brake release during a hill start.		
ASO-OR048	functional	The ASO on-board function shall deliver a defined set of brake commands without the use of emergency braking.		
ASO-OR049	functional	The ASO on-board function shall automatically stop the TU at the planned, calculated and defined Stopping Point.		
ASO-OR050	functional	The ASO on-board function shall be able to stop the shunting composition to a positional accuracy that supports the coupling of wagons with DAC. (in the range between 0,6 to 6 km/h)		
ASO-OR051	functional	Automatic driving shall NOT be disengaged when the TU has stopped at a Stopping Point (Coupling and/or reversing position).		

ASO-OR052	functional	When the TU is being driven automatically, if the Traction Brake Lever is moved to traction the command shall be ignored and the ASO on-board function shall inform the TU operator by an audible warning.		
ASO-OR053	functional	If at a Stopping Point for coupling the DAC-coupling is not executed properly, (i.e. wagon consist is not updated and confirmed properly as planned) the ASO trackside shall perform one other approach automatically.		
ASO-OR054	functional	An indication shall be provided to the TU operator and the YAMS (ASO trackside function) when the wagon set (shunting composition) is not coupled properly.		
ASO-OR055	functional	It shall be reported to the ASO trackside function to indicate when the wagon group is not decoupled properly.		
ASO-OR056	functional	The minimum dwell time defined for each stop shall allow wake up of newly attached wagons, gain enough brake line pressure and to detect updated shunting composition (via FDFTO train function, supported by TAF-TSI wagon data base)		
ASO-OR057	functional	At defined coupling points, if the ASO TU fails to reach the correct Stopping Point within the given tolerance, the ASO trackside function shall automatically adjust the mission and send it to the ASO TU, until the wagons are coupled correctly.		
ASO-OR058	functional	The ASO TU shall be held at the Stopping Point if an "ASO loco hold" request is received by the ASO on-board function.		
ASO-OR059	functional	Automatic movement shall remain engaged on protected Level Crossings.		
ASO-OR060	functional	The ASO trackside function shall be able to switch to another GoA, if it is supported by the ASO onBoard..		
ASO-OR061	functional	The TU Operator (shunting manager) shall be able to select another available GoA on the move.		

ASO-OR62	functional	Automatic driving shall be disengaged automatically when the TU operator applies the operation brakes; or by a specific action on the DMI or when a safe system applies the brakes; but not automatically after a shunting composition has been brought to a standstill.		
ASO-OR63	functional	It shall be possible to inhibit a designated GoA on specific sections of a Yard.		
ASO-OR64	functional	A transition to a lower GoA on the move shall be acknowledged by the person taking on responsibilities for operating the TU before the transition is implemented.		
ASO-OR65	functional	If no acknowledgement of the transition to a lower GoA is received from the TU operator or YAMS after a reaction time, then the ASO on-board function shall brake the TU until the acknowledgement is received or the TU is brought to a standstill.		
ASO-OR66	functional	The ASO on-board function shall disengage automatic driving if it does not have both a valid shunting order / mission or shunting path for the subsequent transfer (shunting order) to carry out. This disengagement can be done on the move.		
ASO-OR67	functional	Automatic disengagement of ASO shall be clearly indicated to the TU operator.		
ASO-OR68	functional	The ASO on-board function shall stop the TU as soon as automatic driving is to become disengaged.		
ASO-OR69	functional	The ASO TU shall be brought to a standstill if it does not have both a valid positioning and a shunting order (missions) for the distances ahead.		
ASO-OR70	functional	When a train safety system applies the emergency brakes, automatic driving shall be automatically disengaged.		
ASO-OR71	functional	It shall be possible to automatically change the movement direction of the TU (i.e., automatic Start of Mission and End of Mission) at a standstill where required by the Shunting order.		
ASO-	functio	Upon detection of change of TU movement direction, the ASO on-board		

OR72	nal	function shall automatically update the required movement distance-based wagon composition length.		
ASO-OR73	functional	The movement direction shall be changed automatically by the ASO on-board function when required for an operational movement by the shunting order.		
ASO-OR74	functional	The ASO function shall support automatic turnback (reversing).		
ASO-OR75	functional	For automatic turnback moves, the movement direction shall only be changed by the ASO on-board function when the TU is stationary or stopped at a defined stopping point in a predefined yard area.		
ASO-OR76	functional	An ASO TU shall commence turnback (reverse) automatically operation automatically or upon receiving a subsequent shunting mission (command) from TU operator or YAMS.		
ASO-OR77	functional	Automatic joining (coupling) of wagons shall be supported by the ASO function.		
ASO-OR78	functional	During approach and before actual joining for coupling, the TU speed shall be continuously controlled, to ensure that it is under the maximum allowed joining speed, up to the joining (coupling) event.  **Figure 63: maximum allowed joining speed**		
ASO-	functio	Automatic joining (coupling) shall commence shortly before the TU is at a		

OR79	nal	standstill at the stopping point (coupling position).		
ASO-OR80	functional	Post joining there shall be an automatic online update of wagon data (train function: detect composition) required also for next ASO mission.		
ASO-OR81	functional	Post joining, the ASO on-board function shall report the new shunting composition to the TU operator and YAMS (train function: detect composition) required also for continuing missions.		
ASO-OR82	functional	Automatic splitting (decoupling) shall commence after the shunting composition gets to a standstill at a defined stopping point without (if it is included in the shunting mission) or optionally after receiving a command from YAMS or the TU-operator.		
ASO-OR83	functional	Automatic splitting shall commence after the TU is at a standstill at the defined stopping point. X		
ASO-OR84	functional	Prior to automatic splitting (decoupling wagons in FDFT shunting mode), the ASO TU shall activate the parking brake of the wagons dedicated for drop off, slightly push and then change direction.		
ASO-OR85	functional	After automatic splitting, the TU shall immediately start the subsequent mission in opposite direction.		
ASO-OR86	functional	Post splitting, there shall be an automatic online update of train data required for ASO for the new wagon composition (train function: detect train composition).		
ASO-OR87	functional	Post splitting the ASO on-board function shall report the new shunting composition (train function: detect train composition) to the TU operator and YAMS.		
ASO-OR88	functional	Intentionally deleted		
ASO-OR89	functional	The ASO trackside function shall display on the DMI the distance to the next stopping position, (de)coupling position or reversing position, considering calculated pushed shunting composition length.		
ASO-	functio	The ASO on-board shall be capable of interfacing with external obstacle		

OR90	nal	detection and railway supervision systems.		
ASO-OR91	functional	The ASO function shall allow the accurate positioning of an ASO fitted consist to align with external freight handling systems for loading and unloading.		
ASO-OR92	functional	The ASO on-board function shall perform self tests periodically when powered to ensure all systems and interfaces necessary for its operation are operating correctly.		
ASO-OR93	functional	Any ASO self-tests shall cover ASO TU in FDFT shunting mode with all attached wagons and not impact systems connected to it.		
ASO-OR94	functional	All self-tests shall be performed automatically, without requiring any additional action by staff.		
ASO-OR95	functional	Selected ASO on-board data shall be remotely accessible in real-time during operation within the ASO area.		
ASO-OR96	functional	All ASO on-board data can be recorded and stored for subsequent retrieval to support maintenance or incident investigations.		
ASO-OR97	functional	In the case of failure of the ASO function it shall be possible to continue operation in manual driving.		
ASO-OR98	functional	The ASO function shall identify any degraded ASO replaceable unit and make the information available to all relevant TUs or infrastructure sub-systems.		
ASO-OR99	functional	If ASO functionality is suppressed, appropriate indications and/or alarms shall be given to the TU operator and YAMS to allow him/her to react and take control of the train.		
ASO-OR100	functional	Operational processes and procedures shall be detailed to manage degraded situations based on the degraded mode operational scenarios.		
ASO-OR101	functional	In the event of a failure affecting ASO functionality the ASO function shall not impact on other safety systems.		
ASO-OR102	functional	In degraded situations, an ASO shunting composition shall be stopped at the next safe location or if not possible, the shunting composition shall automatically be brought to a stand until further instructions / authorisation		

		is provided by the infrastructure.		
ASO-OR103	functional	In the event of fire or smoke detection, once the emergency situation has been resolved, automatic operation shall only be reinstated following a safety command from authorised staff.		
ASO-OR104	functional	Depending on the GoA of the ASO on-board it shall be capable of interfacing with on-board sensors for obstacle detection.		
ASO-OR105	functional	The radio communication shall be secure and shall be executed by authorized persons or devices only.		
ASO-OR106	functional	Control of an ASO On-board (or Lead CCU) shall be assigned exclusively to one entity at any time.		

Additional Requirement: YMSmobile for Flat shunting

The following description will give an example, how the YMSmobile could look like for the support of flat shunting of an operational point of view. The workflow is given by three steps as shown in the following picture.

Figure 64: Overview YMSmobile workflow

The proposed HMI-view is depicted in the following picture. It shows the list of missions and a schematic visualisation of the track scenario with the relevant wagon consists. The scenario in this example is the movement of the wagon W3 from track 5 to the track 113 to form a wagon consist of all three wagons.

The following missions are planned in this example:

1. Movement of the TU outside of point 154.
2. Movement of the TU to track 5 including coupling to W3
3. Movement of the TU with W3 outside of point 154
4. Movement of the TU with W3 to track 113 including coupling to W1
5. TU decouples from wagon consist and moves outside of point 154

Technical requirements from an operational point of view are:

Touch-Display for outdoor use, Power capacity for at least 8 hours shift.

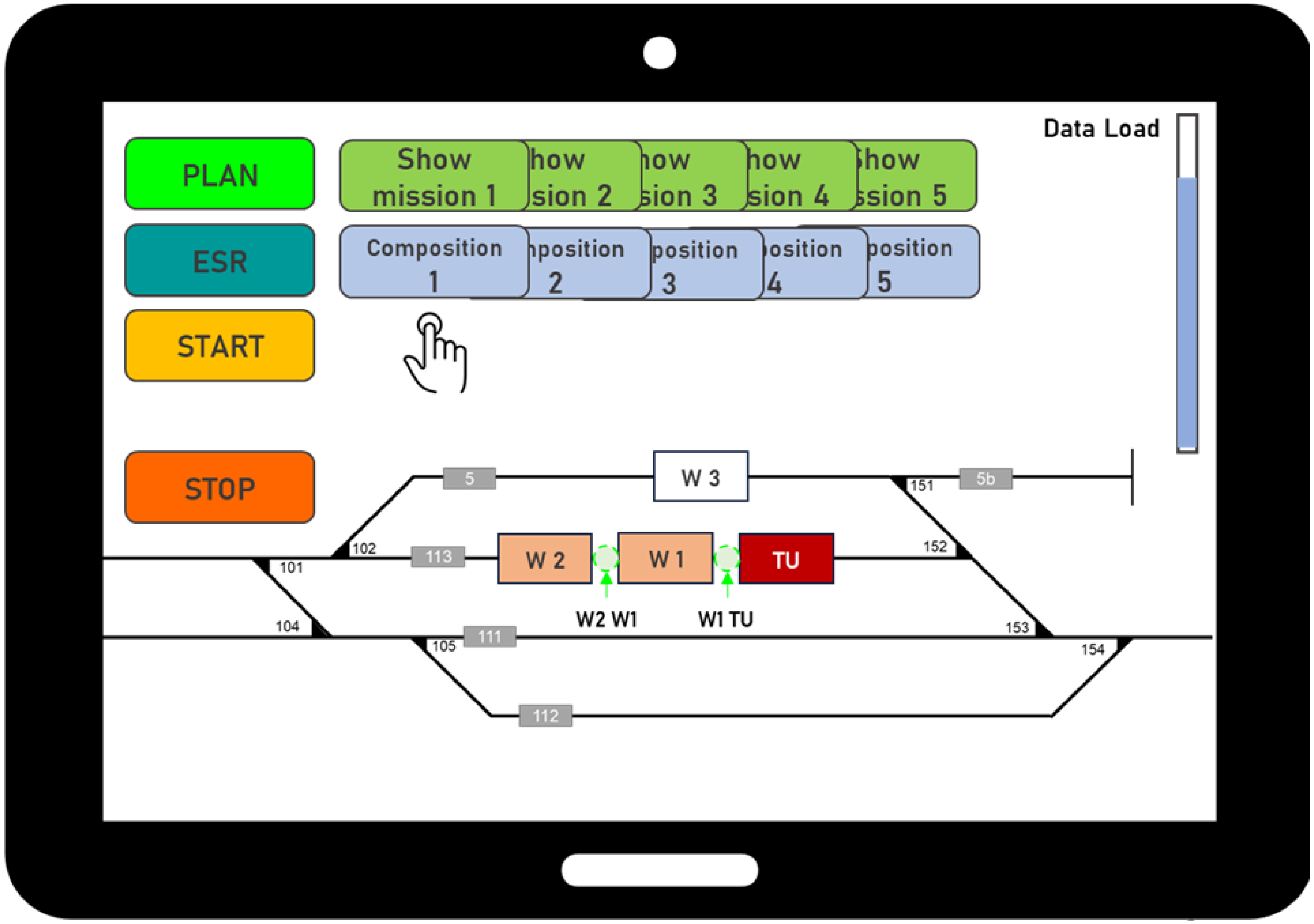


Figure 65: YMSmobile display example

5.5.3 Localization

For approaching a consist in FDFTO Shunting mode, exact positioning is required; it may be followed by coupling or automatic decoupling. Onboard positioning instruments like d-GPS supported by odometry (or equivalent technological solutions) shall reach an exactness of +/-5cm at standstill and need to be available on the traction unit as a leading consist.

For what concerns onboard positioning, EUG & EULYNX partners have evaluated different approaches for providing digital maps. Based on the overall requirements coverage the result was to prefer the Map Service Approach to an integrated approach. Main reason is, that the Map Service Approach is the more scalable one for further use cases, also the available bandwidth can be used more efficiently and even increased by usage of public radio.

Based on that, definition of the required maps for localisation, sometimes also referred to as "digital twin", has recently been elaborated in the clugproject (clugproject.eu). However, it should be clear that positioning in a yard is a less complex problem compared to the problem of finding a suitable positioning solution able to work along everywhere in the European Railway network. Map Data describes the track and trackside infrastructure information, thus providing absolute information of track layout and topological information of the yard. This information can be seen as a sensor and used in the fusion logic to determine the absolute or relative position of the traction unit and the shunting composition.

Taking into account the limited and closed area managed by the YAMS it is logical assuming the availability of differential positioning either as a commercial service or thanks to a dedicated based receiver installed in the yard.

The combination of the yard track map and the precise positioning of the traction units (thanks to the embedded ASO precise positioning system) will allow the ASO trackside to control in real-time the position of the ASO fitted consist.

For what concerns the positioning of the wagons inside the yard for this 1st call of FA5 we will assume to have a black box (part of the architecture in chapter 0) called "analytics" responsible to detect and/or calculate wagon positioning. Nowadays some solutions to detect exact position of wagons in a yard exists (transponders) and others are under development (e.g., machine vision systems exploiting the fact that a yard is a closed systems therefore allowing to install several cameras in fixed position). What is missing today is a common consensus on a standard solution to be deployed5 on track or on-board (of the wagons) or mixing several technologies. The rapid development of aforementioned technologies together with their constant cost decrease will allow us to come to a standard solution to be tested in the next calls.

5.5.3.1 Interface and protocol specifications

Aim of the protocol to be developed within WP5.5 is to define a standard interface protocol to ensure interoperability across manufacturers of different subsystems and components.

In order to guarantee such interoperability between different components present on the yard, both trackside and on-board, an internet protocol (IP) will be used as shown in Figure 54 for wireless and wired communication.

Clearly also other trackside equipment (point machine/level crossings) will be interfaced with same IP protocol.

As consequence of adopting of such standard protocol, it will also be possible to use of commercial off the shelf Radio Modem with significant savings and the possibility to update radio modems in order to follow new wireless developments.

5.5.4 Standardized European Checkpoints towards YMS

The Yard Management System (YMS) can be linked to Standardized European Checkpoints (video gates or wayside checkpoints) to obtain additional information about the status of train composition consists that will arrive in the yard.

The data has to be evaluated in the 2systems responsible for recording. Based on the evaluations, the results are transmitted to the yard management system in form of status information that enables a defined handling of the affected vehicles in the yard. This can be data such as hot runners or damaged wagons, which then have to be treated specially in the yard or e. g. are excluded from further traffic.

For this purpose, discussions are taking place between FDFTO WP 5 (Task 5.6), the Automatic Yards Operations subproject and WP 25 (Task 25.1) to discuss content and interfaces. According to the current timeline, the interfaces will be defined by WP 25 in the course of 2024 to be implemented in the demonstrators in 2025.

In this context, there will be further coordination in order to be able to use these interfaces in the area of "Automatic Yard Operations" in the future.

5.6 Catalogue of Required Amendments to TAF-TSI

To process all the functions that are described in Deliverable 2.1 Preliminary Operational Procedures V1.0 [2] and Deliverable D3.1 System Requirements Specification FDFT V1.0 [7] a lot of information is needed, most of which will be provided via the TAF-TSI Interface. [7] a lot of information is needed, most of which will be provided via the TAF-TSI Interface.

5.6.1 TAF-TSI Interface

How to use the TAF-TSI Interface via the Common Interface (CI) and how to gathering Information from it is described in the following Document (TAF TSI - ANNEX D.2 : APPENDIX E - COMMON INTERFACE [8] (2021-06-15 / Baseline-3.4.0)). Normally One Company uses one CI and then distribute the Information "somehow" in the company. There exists a Reference Implementation of the CI but at the end it is up to the Companies how to use the TAF-TSI Data internally.

5.6.2 TAF-TSI Data and Message Model

The complete TAF-TSI Data and Message Model can be found here (ERA_Technical_Document_TAF-TD-105_D_2_Appendix_F [9] (2023-06-15 / Baseline-3.4.0)). This is the official XSD Schema approved by TAF/TAP TSI Change Control Board (CCB) and published at the ERA in a 1/2 Year rhythm. Besides that, there is the Sector XSD Schema. It is the “candidate” schema where the sector messages are added in order to use the existing global elements of TAF data catalogue. The sector messages are outside of the official TAF data catalogue, and they are owned, used, and maintained by the rail sector. It can be found here (JSG XSD SCEMA)

5.6.3 Assumptions

Today’s newest known Version of TAF-TSI (2023.09.25 2 = Baseline 3.4.0) is implemented.

Rolling Stock Reference Database is in place an contains (at least) all Rolling Stock which is manipulated by the FDFT System.

5.6.4 Required Amendments to TAF-TSI

All in all, we need nearly all the Information provided by TAF-TSI to get FDFTO / YAMS working. What is described in the following is that what must be changed because of the new processes / equipment for the future shunting processes. And therefore, there must be some amendments to the TAF-TSI Data and Message Model:

5.6.4.1 Automated parking brake

In Deliverable 2.1 Preliminary Operational Procedures V1.0 [2] a new function called "Automated Parking Brake" is described. To handle it correctly if a waggon is equipped with it or not it has to mentioned somewhere in the TAF-TSI Data and Message Model.

At the end it is discussable, but the easiest solution will be to add a new element to the element "HandBrakeType" although it is not a Handbrake but has the primary function of it:

Table 38: Amendment to TAF-TSI Element "HandBrakeType"

```
<xs:enumeration value="3">
  <xs:annotation>
    <xs:documentation>"Automated Parking brake</xs:documentation>
  </xs:annotation>
</xs:enumeration>
```

Table 39: Current Version (Baseline 3.4.0) of the TAF-TSI Element "HandBrakeType"

```
<xs:element name="HandBrakeType">
  <xs:annotation>
    <xs:documentation>Classification of hand brake</xs:documentation>
  </xs:annotation>
  <xs:simpleType>
    <xs:restriction base="xs:token">
      <xs:enumeration value="0">
        <xs:annotation>
          <xs:documentation>No hand brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="1">
        <xs:annotation>
          <xs:documentation>Ground-operated hand brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="2">
        <xs:annotation>
          <xs:documentation>Platform-operated hand brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
    </xs:restriction>
  </xs:simpleType>
</xs:element>
```

5.6.4.2 EP Brake

If Waggons will be equipped with an EP Brake, it is necessary to know about. One would say "what for". For the automated brake test there is one difference - The EP Brake System should work much faster than normal air brake. Therefore, the whole Timing for the automated brake test must be different.

The correct element in the TAF-TSI Data and Message Model would be the element "BrakeType":

Table 40: Amendment to TAF-TSI Element "BrakeType"

```
<xs:enumeration value="15">
  <xs:annotation>
    <xs:documentation>G+EA: brake position G which is electrical actuated</xs:documentation>
  </xs:annotation>
</xs:enumeration>
```

Table 41: : Current Version (Baseline 3.4.0) of the TAF-TSI Element "BrakeType"

```
<xs:element name="BrakeType">
  <xs:annotation>
    <xs:documentation>Type of braking system.</xs:documentation>
  </xs:annotation>
  <xs:simpleType>
    <xs:restriction base="xs:token">
      <xs:enumeration value="0">
        <xs:annotation>
          <xs:documentation>G: "Goods" for freight services with slow application and release
times</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="1">
        <xs:annotation>
          <xs:documentation>P: "Passenger" for passenger and freight services with quick application
and release times.</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="2">
        <xs:annotation>
          <xs:documentation>X: an indication that brake system of the freight wagon out of order
(actually / current). Additionally, X cannot be used in Planning.</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="3">
        <xs:annotation>
```

```
          <xs:documentation>R: a subdivision brake position of brake mode "P", for rapid (express)
services with high brake performances</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="4">
        <xs:annotation>
          <xs:documentation>G+E: brake position G with additional brake=electro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="5">
        <xs:annotation>
          <xs:documentation>G+H: brake position G with additional brake=hydro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="6">
        <xs:annotation>
          <xs:documentation>P+E: brake position P with additional brake=electro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="7">
        <xs:annotation>
          <xs:documentation>P+H: brake position P with additional brake=hydro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="8">
        <xs:annotation>
          <xs:documentation>P+Mg: brake position P with additional brake=magnetic track
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="9">
        <xs:annotation>
          <xs:documentation>R+E: brake position R with additional brake=electro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="10">
        <xs:annotation>
          <xs:documentation>R+H: brake position R with additional brake=hydro-dynamic
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="11">
        <xs:annotation>
          <xs:documentation>R+Mg: brake position R with additional brake=magnetic track
brake</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="12">
```

```
            <xs:annotation>
              <xs:documentation>R+WB: brake position R with additional brake=eddy current brake
(German: Wirbelstrombremse)</xs:documentation>
            </xs:annotation>
          </xs:enumeration>
          <xs:enumeration value="13">
            <xs:annotation>
              <xs:documentation>R+E+Mg: brake position R with additional brake=electro-dynamic brake
and magnetic track brake</xs:documentation>
            </xs:annotation>
          </xs:enumeration>
          <xs:enumeration value="14">
            <xs:annotation>
              <xs:documentation>R+E+WB: brake position R with additional brake=electro-dynamic brake
and eddy current brake</xs:documentation>
            </xs:annotation>
          </xs:enumeration>
        </xs:restriction>
      </xs:simpleType>
    </xs:element>
```

5.6.4.3 CouplingType

In the current Baseline of the TAF-TSI (ERA_Technical_Document_TAF-TD-105_D_2_Appendix_F [9] (2023-06-15 / Baseline-3.4.0)) a DAC is not mentioned. What is mentioned in the Element "CouplingType" is an "automatic coupling". This is insufficient for our needs. We need the exact Version of the DAC, therefore we have to add some new elements to the Element "CouplingType":

Table 42: Amendment to TAF-TSI Element "CouplingType"

```
<xs:enumeration value="5">
  <xs:annotation>
    <xs:documentation>DAC Type 4</xs:documentation>
  </xs:annotation>
</xs:enumeration>
<xs:enumeration value="6">
  <xs:annotation>
    <xs:documentation>DAC Type 4.5</xs:documentation>
  </xs:annotation>
</xs:enumeration>
<xs:enumeration value="7">
  <xs:annotation>
    <xs:documentation>DAC Type 5</xs:documentation>
  </xs:annotation>
</xs:enumeration>
```

Table 43: Current Version (Baseline 3.4.0) of the TAF-TSI Element "CouplingType"

```
<xs:element name="CouplingType">
  <xs:annotation>
    <xs:documentation>Classification of coupling</xs:documentation>
  </xs:annotation>
  <xs:simpleType>
    <xs:restriction base="xs:token">
      <xs:enumeration value="0">
        <xs:annotation>
          <xs:documentation>without coupler</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="1">
        <xs:annotation>
          <xs:documentation>non-reinforced coupler less than 85t</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="2">
        <xs:annotation>
          <xs:documentation>reinforced coupler equals to 85t</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="3">
        <xs:annotation>
          <xs:documentation>ultra-reinforced coupler greater than 85t</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
      <xs:enumeration value="4">
        <xs:annotation>
          <xs:documentation>automatic coupling</xs:documentation>
        </xs:annotation>
      </xs:enumeration>
    </xs:restriction>
  </xs:simpleType>
</xs:element>
```

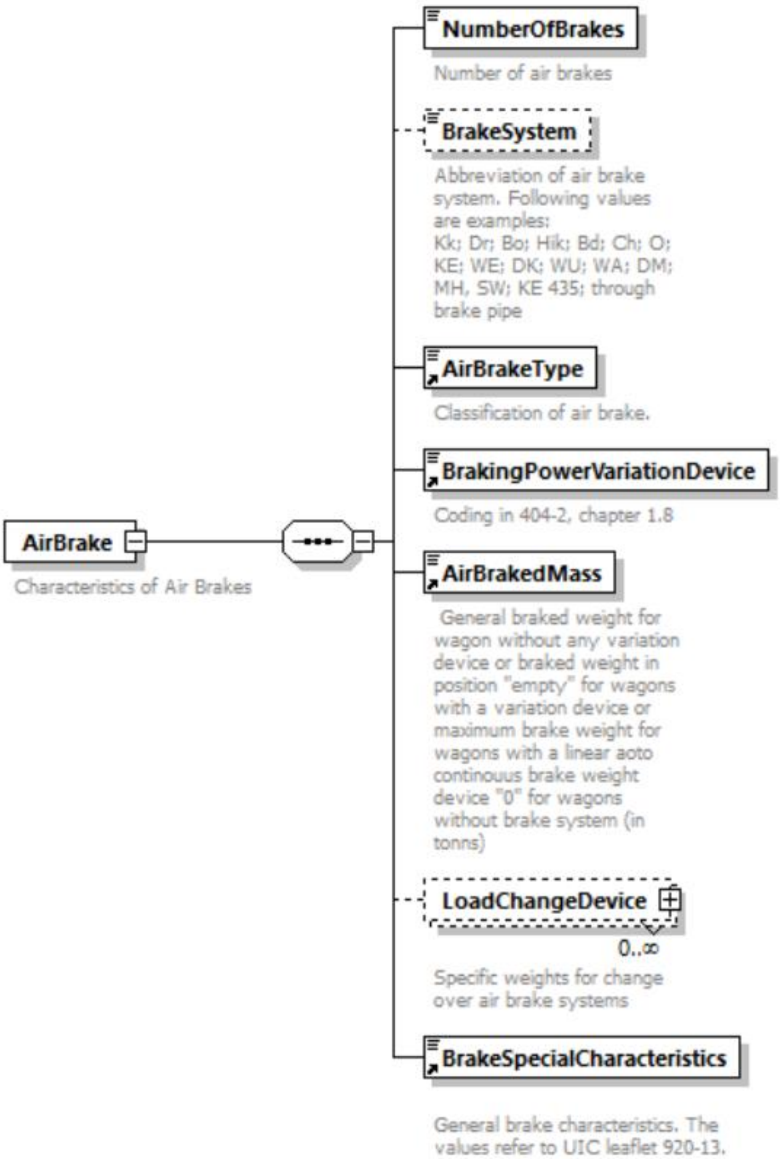
5.6.4.4 Function to keep running capability (unnecessity for bleeding / venting)

In some cases, like on a hump we need wagons without any connection to a loco to run down the hump without any possibility that the brake will do something. That currently is assured by bleeding of the wagons which is a manual and time-consuming process. Therefore, there is an ongoing discussion about a new function that would make the venting / bleeding obsolete. However this function is currently under consideration and development within WP5, but not yet available.

As this is a new function it cannot be added to an existing element. The cleanest solution would be to add a new sub-element to the element "AirBrake":

Table 44: Amendment – new Sub-Element (NoBleedingNeeded) to TAF-TSI Element "AirBrake"

```
<xs:element name="NoBleedingNeeded" type="xs:boolean">
  <xs:annotation>
    <xs:documentation>No bleeding needed on this wagon</xs:documentation>
  </xs:annotation>
</xs:element>
```



F

Figure 66: Current Version (Baseline 3.4.0) of the TAF-TSI Element "AirBrake"

5.6.4.5 ShuntingCC_System & ShuntingRadioSystem

For the Train run purpose there are several elements defined. One is about the Train Control and Command System (TrainCC_System). Another is about the Train Radio System (TrainRadioSystem).

When it comes to shunting as is envisioned in TRANS4M-R that information is a feature of the yard (and a shunting traction unit). So, it will make sense to put this information as a sub-element to the existing element "LocationPrimaryInformation". It also will make sense to code values for this purpose. So, the new elements would look like:

Table 45: Amendment – new Sub-Element (ShuntingCC_System) to TAF-TSI Element " LocationPrimaryInformation"

```xml
<xs:element name="ShuntingCC_System" type="ShuntingCC_SystemCode">
  <xs:annotation>
    <xs:documentation>Identifies the shunting command control system of a location in coded values.
    </xs:documentation>
  </xs:annotation>
</xs:element>
```

Table 46: Amendment – new Sub-Element (ShuntingRadioSystem) to TAF-TSI Element " LocationPrimaryInformation"

```xml
<xs:element name="ShuntingRadioSystem" type="ShuntingRadioSystemCode">
  <xs:annotation>
    <xs:documentation>Identifies the shunting radio system of a location in coded values.
    </xs:documentation>
  </xs:annotation>
</xs:element>
```

This is the similar Information for Train run:

Table 47: Existing TAF-TSI Element " TrainCC_System "

```xml
<xs:element name="TrainCC_System" type="TrainCC_SystemCode">
  <xs:annotation>
    <xs:documentation>Identifies the command control system of the train in coded values.
    </xs:documentation>
  </xs:annotation>
</xs:element>
```

Table 48: Existing TAF-TSI Element " TrainRadioSystem "

```xml
<xs:element name="TrainRadioSystem">
  <xs:annotation>
    <xs:documentation>The onboard radio system of the train in coded format
    </xs:documentation>
  </xs:annotation>
  <xs:simpleType>
    <xs:restriction base="xs:token">
```

```
        <xs:enumeration value="1"/>
        <xs:enumeration value="2"/>
      </xs:restriction>
    </xs:simpleType>
  </xs:element>
```

5.6.4.6 Automated Stationary Brake Test & Stationary / Trackside parking brake

Although the two devices mentioned in this headline are not nearly the same, the way how to deal with them is. Therefore, in this chapter we can apply the same logic for both challenges.

When a Yard is equipped with Automated Stationary Brake Test Devices or Stationery / Trackside parking brake, it must be known to the train operator, as it saves a lot of manual workload to the staff. Manly that information will be Boolean because a yard is either equipped or not with such devices. The exact (geographical) location of such a device cannot be described adequately via TAF-TSI.

As it is a feature of the Yard, it makes sense to put this information as a sub-element to the existing element "LocationPrimaryInformation". As the information is Boolean it will look like:

Table 49: Amendment – new Sub-Element (AutomatedStationaryBrakeTestEquipped) to TAF-TSI Element " LocationPrimaryInformation"

```
<xs:element name="AutomatedStationaryBrakeTestEquipped" type="xs:boolean">
  <xs:annotation>
    <xs:documentation>This Yard is equipped with Automated Stationary Brake Test Device(s)
    </xs:documentation>
  </xs:annotation>
</xs:element>
```

Table 50: Amendment – new Sub-Element (StationaryParkingBrake) to TAF-TSI Element " LocationPrimaryInformation"

```
<xs:element name="StationaryParkingBrake" type="xs:boolean">
  <xs:annotation>
    <xs:documentation>This Yard is equipped with stationary parking brake(s)
    </xs:documentation>
  </xs:annotation>
</xs:element>
```

6 Conclusions

In this document the focus is on the requirements of how to make best use of the DAC and its enabler functions in order to automate operation in yard areas. Automated Shunting Operation is summarized under the acronym of ASO, in this deliverable focusing on automated shunting movements. ASO is only applicable in FDFTO shunting mode, uses FDFTO train functions, but does not support train runs itself.

The two core, general use-cases named “hump shunting” and “flat shunting” and the requirements for automating them is described in many details. While shunting in a hump yard is basically a one-directional workflow, it needs a different operational approach and will allow a higher degree of automation than shunting in a flat yard, with a never-ending variety of possible scenarios in the yard and its connected last mile.

The aim of this Deliverable is to specify the requirements for the provision of competitive digital rail freight services through yard automation supporting Full Digital Freight Train Operation. Fully Automated Decoupling and Automated Shunting Movements have been identified as the key enablers for automation in yards. Stationary brake test installments and stationary parking brake being supportive devices until operational target processes can be reached through full implementation of all related FDFTO-train functions. A modular approach was chosen to later allow a stepwise introduction of the described technical enablers, which should finally help supporting the DAC migration.

While the authors suggest that the planned objectives of the task have been achieved, it seems clear that there will be a need for continued interaction and flexibility within the project and its work packages but also to adapt to System Pillar outputs, and vice versa.

7 References

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8 Appendices

8.1 EEIG ERTMS Users Group CCS Use Case Specification and Basic Requirements for the Intelligent Freight Train based on the DAC

		Stakeholder	Lead	Scope
Automatic train initialisation				
3.1.1	Automatic wagon list creation	CCS RU	RU	On-board Remote
3.1.2	Train length determination (as input to SS026 7.5.1.56 L_TRAIN)	CCS RU	CCS	On-board
3.1.3	Train composition determination	CCS RU	CCS	On-board
Train Integrity Monitoring				
4.1.1	On-board Train Integrity Monitoring (as input to SS026 7.5.1.112 Q_LENGTH)	CCS RU	CCS	On-board
4.1.2	Safe Train Length Determination (as input to SS026 7.5.1.57 L_TRAININT)	CCS RU	CCS	On-board
Automatic brake test				

Not described in this document	Automatic conduction of the brake test	RU Brake experts	RU	On-board

Automatic maximal speed and braking performance determination

5.1.1	Automatic determination and provision of maximal speed	CCS RU	CCS	On-board Remote
5.1.2	Automatic determination and provision of braking performance	CCS RU	CCS	On-board Remote
5.1.3	Automatic brake sheet creation	RU	RU	On-board Remote
5.1.4	Automatic loading weight detection	CCS RU	RU	On-board Remote

Applying and releasing of the ep-brake

Not described in this document	Applying and releasing braking forces using ep-brake	CCS RU Brake experts	RU	On-board

Source: EEIG ERTMS Users Group CCS Use Case Specification and Basic Requirements for the Intelligent Freight Train based on the DAC

Ref: Version: Date: 21E158 1.0 06/09/2021

8.2 Regular ATO Scenario list.

S2R X2Rail4 ATO scenarios Relation to Yard / YAMS USE CASES

Scenario ID Scenario Name	
R1 Automatic wake-up train	to be aligned with FPSE;
R2 Compose train	Wagon Processing description will be provided
R3 Prepare train for mission	= train preparation, FPSE; EG train functions
R4 Prepare train for departure	= train preparation, FPSE; EG train functions
R5 Drive according to journey	not applicable (no journey / no timetable)
R6 React to journey update	not applicable; no journey profile
R7 React to mission update	not applicable; no mission profile
R8 Level crossing	t.b.d.
R9 Passenger request stop	not applicable; no passengers
R10 Train stops at stopping point	not applicable (as train); for TU in Shunting Mode will be defined
R11 Ending journey	not applicable (no journey / no timetable)
R12 Ending mission	not applicable / no train mission) for TU in Shunting Mode will be defined
R13 Shutdown train	to be aligned with FPSE; EG train functions
R14 Passengers embark and disembark	not applicable / no passengers
R15 Load and unload cargo	not specified / not in scope of Demo
R16 Joining trains	under ATO / no ASO topic
R17 Splitting trains	under ATO / no ASO topic
R18 Change cabin	under ATO / not applicable / center cabin
R19 Change of train running number	under ATO / not applicable
R20 Change running direction	change movement direction
R21 GoA transitions	under ATO / depending on GoA definitions
R22 Train Management handover	not applicable / no train
R23 TMS handover	not applicable / no train
R24 ATO inhibition	t.b.d.
R25 C-DAS inhibition	not applicable / no speed profile

R26 Neutral / Powerless Sections t.b.d.

R27 Change in adhesion condition t.b.d.

R28 Transition from ATP Class B area to Class A area t.b.d.

R29 Transition from ATP Class A area to Class B area t.b.d.

R30 Drive inside depot / stabling or maintenance facility not applicable

R31 Automatic cleaning (washing machine) not applicable

R32 Manual cleaning at standstill not applicable / customer task

R34 Driving according to journey based on lateral signalling t.b.d.

R35 Remote operation in yards, depots, and stabling areas
Remote operation in Yards via YAMS, YAMSmobile

Source: X2Rail4 Regular ATO Operational Scenarios list, commented

9 List of Figures

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